FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMONG MEN

PER ORBEM

SMITHSONIAN INSTITUTION

WASHINGTON 1846

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ANNUAL REPORT OF THE
BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30, 1916.

SMITHSONIAN INSTITUTION,
Washington, December 21, 1916.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1916. I have the honor to be,

Very respectfully, your obedient servant,

CHARLES D. WALCOTT, *Secretary.*

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2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1916.

3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1916.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1916.

THE SMITHSONIAN INSTITUTION.

June 30, 1916.

Presiding officer ex officio.—WOODROW WILSON, President of the United States.
Chancellor.—EDWARD DOUGLASS WHITE, Chief Justice of the United States.
Members of the Institution:

WOODROW WILSON, President of the United States.
THOMAS R. MARSHALL, Vice President of the United States.
EDWARD DOUGLASS WHITE, Chief Justice of the United States.
ROBERT LANSING, Secretary of State.
WILLIAM GIBBS MCADOO, Secretary of the Treasury.
NEWTON DIEHL BAKER, Secretary of War.
THOMAS WATT GREGORY, Attorney General.
ALBERT SIDNEY BURLESON, Postmaster General.
JOSEPHUS DANIELS, Secretary of the Navy.
FRANKLIN KNIGHT LANE, Secretary of the Interior.
DAVID FRANKLIN HOUSTON, Secretary of Agriculture.
WILLIAM COX REDFIELD, Secretary of Commerce.
WILLIAM BAUCHOP WILSON, Secretary of Labor.

Regents of the Institution:

EDWARD DOUGLASS WHITE, Chief Justice of the United States, Chancellor.
THOMAS R. MARSHALL, Vice President of the United States.
HENRY CABOT LODGE, Member of the Senate.
WILLIAM J. STONE, Member of the Senate.
HENRY FRENCH HOLLIS, Member of the Senate.
SCOTT FERRIS, Member of the House of Representatives.
ERNEST W. ROBERTS, Member of the House of Representatives.
JAMES T. LLOYD, Member of the House of Represenattives.
ANDREW D. WHITE, citizen of New York.
ALEXANDER GRAHAM BELL, citizen of Washington, D. C.
GEORGE GRAY, citizen of Delaware.
CHARLES F. CHOATE, Jr., citizen of Massachusetts.
JOHN B. HENDERSON, Jr., citizen of Washington, D. C.
CHARLES W. FAIRBANKS, citizen of Indiana.

Executive committee.—GEORGE GRAY, ALEXANDER GRAHAM BELL, ERNEST W. ROBERTS.
Secretary of the Institution.—CHARLES D. WALCOTT.
Assistant secretary.—RICHARD RATHBUN.
Chief Clerk.—HARRY W. DORSEY.
Accountant and disbursing agent.—W. I. ADAMS.
Editor.—A. HOWARD CLARK.
Assistant librarian.—PAUL BROCKETT.
Property clerk.—J. H. HILL.

THE NATIONAL MUSEUM.

Keeper ex officio.—CHARLES D. WALCOTT, Secretary of the Smithsonian Institution.

Assistant secretary in charge.—RICHARD RATHBUN.

Administrative assistant.—W. DE C. RAVENEL.

Head curators.—WILLIAM H. HOLMES, LEONHARD STEJNEGER, G. P. MERRILL.

Curators.—PAUL BARTSCH, R. S. BASSLER, A. HOWARD CLARK, F. W. CLARKE, F. V. COVILLE, W. H. DALL, CHESTER G. GILBERT, WALTER HOUGH, L. O. HOWARD, ALEŠ HRDLIČKA, FREDERICK L. LEWTON, GEORGE C. MAYNARD, GERRIT S. MILLER, Jr., ROBERT RIDGWAY.

Associate curators.—J. C. CRAWFORD, W. R. MAXON, DAVID WHITE.

Curator, National Gallery of Art.—W. H. HOLMES.

Chief of correspondence and documents.—RANDOLPH I. GEARE.

Disbursing agent.—W. I. ADAMS.

Chief of exhibits (Biology).—JAMES E. BENEDICT.

Superintendent of buildings and labor.—J. S. GOLDSMITH.

Editor.—MARCUS BENJAMIN.

Assistant librarian.—N. P. SCUDDER.

Photographer.—T. W. SMILLIE.

Registrar.—S. C. BROWN.

Property clerk.—W. A. KNOWLES.

Engineer.—C. R. DENMARK.

BUREAU OF AMERICAN ETHNOLOGY.

Ethnologist-in-charge.—F. W. HODGE.

Ethnologists.—J. WALTER FEWKES, JOHN P. HARRINGTON, J. N. B. HEWITT, FRANCIS LA FLESCHE, TRUMAN MICHELSON, JAMES MOONEY, JOHN R. SWANTON.

Special ethnologist.—LEO J. FRACHTENBERG.

Honorary philologist.—FRANZ BOAS.

Editor.—JOSEPH G. GURLEY.

Librarian.—ELLA LEARY.

Illustrator.—DE LANCEY GILL.

INTERNATIONAL EXCHANGES.

Chief clerk.—C. W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK.

Superintendent.—FRANK BAKER.

Assistant Superintendent.—A. B. BAKER.

ASTROPHYSICAL OBSERVATORY.

Director.—C. G. ABBOT.

Aid.—F. E. FOWLE, Jr.

Bolometric assistant.—L. B. ALDRICH.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFC LITERATURE.

Assistant in charge.—LEONARD C. GUNNELL.

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

CHARLES D. WALCOTT,

FOR THE YEAR ENDING JUNE 30, 1916.

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit herewith the customary annual report on the operations of the Smithsonian Institution and its branches during the fiscal year ending June 30, 1916, including work placed by Congress under the direction of the Board of Regents in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, and the United States Bureau of the International Catalogue of Scientific Literature.

The general report reviews the affairs of the Institution proper and briefly summarizes the operations of its several branches, while the appendices contain detailed reports by the assistant secretary and others directly in charge of various activities. The reports on operations of the National Museum and the Bureau of American Ethnology will also be published as independent volumes.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

The Smithsonian Institution was created an establishment by act of Congress approved August 10, 1846. Its statutory members are the President of the United States, the Vice President, the Chief Justice, and the heads of the executive departments.

THE BOARD OF REGENTS.

The Board of Regents, which is charged with the administration of the Institution, consists of the Vice President and the Chief Justice of the United States as ex officio members, three Members of the Senate, three Members of the House of Representatives, and six citizens, "two of whom shall be residents in the city of Washington and the other four shall be inhabitants of some State, but no two of them from the same State."

In regard to the personnel of the board the only change during the fiscal year was the appointment of James T. Lloyd, Representative from Missouri. The roll of Regents on June 30, 1916, was as follows: Edward D. White, Chief Justice of the United States, Chancellor; Thomas R. Marshall, Vice President of the United States; Henry Cabot Lodge, Member of the Senate; William J. Stone, Member of the Senate; Henry French Hollis, Member of the Senate; Scott Ferris, Member of the House of Representatives; Ernest W. Roberts, Member of the House of Representatives; James T. Lloyd, Member of the House of Representatives; Andrew D. White, citizen of New York; Alexander Graham Bell, citizen of Washington, D. C.; George Gray, citizen of Delaware; Charles F. Choate, jr., citizen of Massachusetts; John B. Henderson, jr., citizen of Washington, D. C.; and Charles W. Fairbanks, citizen of Indiana.

The board held its annual meeting on December 9, 1915. The proceedings of that meeting, as also the annual financial report of the executive committee, have been printed, as usual, for the use of the Regents, while such important matters acted upon as are of public interest are reviewed under appropriate heads in the present report of the Secretary. A detailed statement of disbursements from Government appropriations, under the direction of the Institution for the maintenance of the National Museum, the National Zoological Park, and other branches, will be submitted to Congress by the Secretary in the usual manner in compliance with the law.

FINANCES.

The permanent fund of the Institution and the sources from which it was derived are as follows:

Deposited in the Treasury of the United States.

Bequest of James Smithson, 1846		$515,169.00
Residuary legacy of James Smithson, 1867		26,210.63
Deposit of savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000	
Accumulated interest on Hamilton fund, 1895	1,000	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins, 1907		7,918.69
Deposit from savings of income, 1913		636.94
Part of bequest of William Jones Rhees, 1913		251.95
Deposit of proceeds from sale of real estate (gift of Robert Stanton Avery), 1913		9,692.42
Bequest of Addison T. Reid, 1914		4,795.91
Deposit of savings from income, Avery bequest, 1914		204.09

Deposit of savings from income, Avery fund, 1915	$1,862.60
Deposit of savings from income, Reid fund, 1915	426.04
Deposit of balance of principal, $248.05, and income, $28.39, Rhees fund, 1915	276.44
Deposit of first payment of Lucy T. and George W. Poore fund, 1915	24,534.92
Deposit of part of principal of Addison T. Reid fund, 1916	4,698.59
Deposit of principal of George H. Sanford fund, 1916	1,020.00
Deposit of savings from income, 1916	2,681.41
Total of fund deposited in the United States Treasury	996,000.00

Other resources.

Registered and guaranteed 4 per cent bonds of the West Shore Railroad Co., part of legacy of Thomas G. Hodgkins (par value)	42,000.00
Coupon 5 per cent bonds of the Brooklyn Rapid Transit Co., due July 1, 1918 (cost)	5,040.63
Coupon 6 per cent bonds of the Argentine Nation, due Dec. 15, 1917 (cost)	5,093.75
Total permanent fund	1,048,134.38

The second installment to the Addison T. Reid fund, amounting to $4,698.59, and a bequest to be known as the George H. Sanford fund, amounting to $1,020, were added during the year to the permanent fund deposited in the Treasury of the United States, which, together with incomes of several specific funds amounting to $2,681.41, now aggregates the total sum of $996,000, which bears interest at the rate of 6 per cent per annum.

The sum of $10,000, being a part of the bequest designated as the Frances Lea Chamberlain fund, the income of which is to be applied to the maintenance of the Isaac Lea collection of gems and mollusks in the National collections, was received by the Institution in October, 1915, and on the advice of the executive committee was invested in gold notes maturing on December 15, 1917, and July 1, 1918. These investments form a nucelus of what will hereafter be known as the consolidated fund. The income account of each specific fund will be credited with the proportion of income which each invested fund bears to the whole fund.

The income of the Institution during the year, amounting to $107,670.26, was derived as follows: Interest on the permanent foundation, $60,751.23; contributions from various sources for specific purposes, $22,954.99; first payment of the Frances Lea Chamberlain fund, $10,000; second payment on account of the Addison T. Reid fund, $4,698.59; and from other miscellaneous sources, $9,265.45.

Adding the cash balance of $42,165.86 on July 1, 1915, the total resources for the fiscal year amounted to $149,836.12. The disbursements, which are given in detail in the annual report of the executive

committee, amounted to $105,125.10, leaving a balance of $44,711.02 on deposit June 30, 1916, in the United States Treasury and in cash.

The Institution was charged by Congress with the disbursement of the following appropriations for the year ending June 30, 1916:

International exchanges	$32,000
American ethnology	42,000
Astrophysical Observatory	13,000
National Museum:	
Furniture and fixtures	25,000
Heating and lighting	46,000
Preservation of collections	300,000
Books	2,000
Postage	500
Building repairs	15,000
Bookstacks for Government bureau libraries	6,500
National Zoological Park	100,000
International Catalogue of Scientific Literature	7,500
Total	589,500

In addition to the above specific amounts to be disbursed by the Institution there was included under the general appropriation for printing and binding an allotment of $76,200 to cover the cost of printing and binding the Smithsonian annual report, and reports and miscellaneous printing for the Government branches of the Institution.

THE FREER ART GALLERY.

One of the most important events since the foundation of the Institution was consummated in December last. In my last report it was mentioned that Mr. Charles L. Freer was considering the question of erecting a suitable building for the permanent preservation of the splendid collection of objects of art which he presented to the Institution in 1906 and has since augmented by many further gifts. It is exceedingly gratifying here to record the gift by Mr. Freer of $1,000,000 in cash for the immediate erection of a building and that the site and preliminary plans have been agreed upon, so that the actual construction work will soon begin. The building will be of granite and located at the southwest corner of the Smithsonian reservation at Twelfth and B Streets.

The munificent donation by Mr. Freer of his collection and provision for its preservation is unsurpassed in this country, and is one of the most notable gifts of its character in the world's history.

Mr. Freer describes his collection as follows:

> These several collections include specimens of very widely separated periods of artistic development, beginning before the birth of Christ and ending to-day. No attempt has been made to secure specimens from unsympathetic sources, my collecting having been confined to American and Asiatic schools. My great

desire has been to unite modern work with masterpieces of certain periods of high civilization harmonious in spiritual and physical suggestion, having the power to broaden esthetic culture and the grace to elevate the human mind.

The original collection consisted of about 2,300 paintings and other objects of art, and has since been increased to 5,346 items, including American paintings and sculptures, the Whistler collection, and oriental paintings, pottery, bronzes, and jades from China, Korea, Japan, and other Asiatic countries.

A full catalogue of items is given by Mr. Rathbun in his Museum Bulletin on the National Gallery of Art.

EXPLORATIONS AND RESEARCHES.

The usual activities were continued during the past year in advancing one of the fundamental objects of the Smithsonian Institution, the *increase of knowledge*. In this work various explorations and researches were inaugurated or participated in by the Institution and its branches, covering practically all divisions of astronomical, anthropological, biological, and geological science. The extent of these explorations and researches during the history of the Institution covers a wide range, although a great deal more of most important work could have been accomplished had adequate funds been available. Friends of the Institution have generously aided this work, particularly during the last few years, through the contribution of funds for specific purposes, but much yet remains undone, and opportunities for undertaking important lines of investigation are constantly being lost through lack of means to carry them into execution.

Several proposed expeditions to various parts of the world have been temporarily delayed by the war in Europe.

I will here mention only briefly some of the recent activities of the Institution in these directions and for details of other investigations may refer to the appendices containing the reports of those directly in charge of the several branches of the Institution.

GEOLOGICAL EXPLORATIONS IN THE ROCKY MOUNTAINS.

In continuation of my previous work in the Rocky Mountain region, I was engaged during the season of 1915 in field investigation in the Yellowstone Park area and from there north into the Belt Mountains east of Helena, Mont. The work in the Yellowstone Park was carried on with two objects in view:

First. To determine, if possible, the extent to which the lower forms of algæ and possibly bacteria contributed, through their activities, to the deposition from the geyser and hot spring waters of the contained carbonate of lime and silica.

Second. The securing for the National Museum of a series of geyser and hot spring deposits, also silicified wood from the petrified forests and certain types of volcanic rocks.

During the investigation and collecting, numerous photographs were taken of geysers and hot springs and of deposits made from the waters through evaporation and organic agencies.

The collections were brought to the camps by pack horses and buckboard and subsequently packed for shipment at Fort Yellowstone and Yellowstone. Material assistance was afforded by the cooperation of the acting superintendent of the park, Col. L. M. Brett, United States Army, and officers of the United States Engineer Corps in charge of the maintenance and development of the park roads and trails.

Upward of 5 tons of specimens were collected and shipped to the National Museum. This collection permits of the preparation of a special Yellowstone Park exhibit of great beauty and interest.

It was found that algal growth was everywhere present when the temperature of the waters was from 70° to not much above 180° F., and that this growth had a marked effect upon the amount and character of both calcareous and siliceous deposits.

After completing the investigation of the geyser and hot spring deposits, a trip was made to the Fossil Forest in the northeastern section of the park, in the Lamar River Valley. Large collections were made here of silicified wood and various minerals, one of the latter being a remarkable and beautiful form of calcite rosettes, which were illustrated and technically described in the pamphlet on Smithsonian explorations in 1915.[1]

The camp site in the Lamar Valley was one of unusual interest and beauty. The high hills to the south showed the rock cliffs containing silicified woods, calcite rosettes, and beautiful specimens of chalcedony. A little way from the camp the party met with a large herd of bison grazing freely in the broad open valley; also herds of elk, bands of antelope, a few black bear, and an occasional wolf.

On leaving the park, after 675 miles of travel with the camp outfit, the party proceeded down the West Gallatin River Canyon, stopping to examine the section of Cambrian rocks at the mouth of Squaw Creek. The next permanent camp was made in Deep Creek Canyon, 17 miles east of Townsend, Mont., where the extensive pre-Cambrian sections of the Big Belt Mountains are beautifully shown. About 2 tons of pre-Cambrian specimens were collected in this vicinity before the storms of late September (1915) closed the season's field work.

[1] Smithsonian Miscellaneous Collections, Vol. 66, No. 3, 1916.

MASTODON FROM INDIANA.

Many finds of mastodon and mammoth remains, especially from different localities in States bordering on the Great Lakes, are constantly being reported to the Institution. These "finds," chiefly in swamp deposits of the Pleistocene, generally consist of a few isolated bones or teeth, but afford evidence of an abundance of these great creatures during the geological age just preceding the present. Compared, however, with the great number of remains found, complete skeletons are rare, principally because the finds are generally brought to light by workmen who have little or no knowledge of the scientific value of the remains. The National Museum was therefore fortunate during the past year in the acquisition of a fine, nearly complete adult male mastodon skeleton from a swamp deposit in northwestern Indiana.

A part of the skull, four limb bones, a few ribs and vertebræ were unearthed by a dredge crew while excavating a drainage canal and shipped to the Institution. Mr. J. W. Gidley, of the National Museum, later succeeded in finding the lower jaws, most of the remaining vertebræ and ribs, parts of the pelvis, and a few more limb and foot bones, and on a second visit found the missing sections of the vertebral column, several more foot bones, and other important fragments. On assembling all the bones recovered it has been found that, with comparatively little artificial restoration, an unusually fine and complete specimen of the American mastodon can be prepared for exhibition.

PALEONTOLOGICAL AND STRATIGRAPHIC STUDIES IN THE PALEOZOIC ROCKS.

Dr. E. O. Ulrich of the National Museum, was occupied for several months during the field season of 1915, under the auspices of the United States Geological Survey, in a study of the lower Paleozoic deposits of the Mississippi Valley. He was engaged chiefly in seeking evidence respecting the boundary line between the Cambrian and Ozarkian systems. For this purpose many of the outcrops of these rocks were visited, but the most important evidence was found in the upper Mississippi Valley and in the Missouri where the Upper Cambrian rocks are particularly well displayed, and the succeeding deposits of the Ozarkian system are more commonly fossiliferous than elsewhere. The relative abundance of fossils in these areas permitted the actual boundary between the two systems to be accurately determined after considerable study. This boundary was found to coincide with the uneven plane formed at the junction of the deposits laid down by the retreating Cambrian sea with those formed by the return of the waters in the succeeding Ozarkian time. During the progress of these stratigraphic studies

numerous collections of fossils were secured for the museum series, and incidentally the investigations resulted in the proper placement of many fossils whose stratigraphic position had hitherto been uncertain.

In the latter part of the season Dr. Ulrich worked out the field relations of some insufficiently located collections of Paleozoic fossils made in southwest Virginia at various times in the past. The most important result of these investigations is the proof that a large coral fauna, exceedingly like that which marks the horizon of the Onondaga limestone throughout the extent of this well known and widely distributed Middle Devonian formation, had already invaded the continental basins as far as southwest Virginia during the closing stages of the preceding Lower Devonian. This instance of recurring fossil faunas is regarded as one of the most important of the many similar instances that have been established through the field studies of Dr. Ulrich during the past 25 years. All have served in correcting erroneous correlations of formations that had arisen through the confusion of earlier or later appearances of faunas with the one recognized in the standardized sequence of stratigraphic units.

Mr. R. D. Mesler, under the supervision of Dr. Ulrich, spent the summer of 1915 in making collections of Ordovician and Silurian fossils from formations and localities in the Appalachian and Mississippi Valleys which had hitherto been little represented in the museum collections. A large number of fossils resulted from his trip, particularly from the Middle Ordovician rocks of east Tennessee, which will form the basis of a future monograph on the paleontology of that region.

EXPLORATIONS IN SIBERIA.

Through the liberality of the Telluride Association the Institution was enabled to send Mr. B. Alexander with the Koren Expedition to the Kolyma River region of northern Siberia. The expedition left Seattle, Wash., in June, 1914, and returned in September, 1915. The immediate purpose of the trip was to obtain remains of large extinct animals, particularly of the mammoth for which the region is noted. The results were not all that were hoped for, but a considerable quantity of material was obtained, though no complete skeleton. A report, with photographs taken by the party, was published in the pamphlet on Smithsonian explorations and field work in 1915. The collection of bones sent in by the expedition contains a few fine specimens, together with a considerable number of isolated bones, which are valuable for study and comparison. They all indicate a late Pleistocene age, as the bones of many of the forms represented can with difficulty be distinguished from those of species still living in

that region. The animals represented include the mammoth, bison, caribou, horse (two or more species), rhinoceros, musk-ox, wolverine, and wolf. The prize specimen is a finely preserved, almost complete skull of *Elephas primigenius*. It is of especial interest as being the only skull of the Siberian mammoth in any of our American museums.

COLLECTING FOSSIL ECHINODERMS IN THE OHIO VALLEY.

Explorations for fossil echinoderms were conducted during the summer of 1915, under the supervision of Mr. Frank Springer, associate in paleontology in the United States National Museum. The work was limited to two areas of Silurian rocks in the Ohio Valley from each of which much valuable material was procured for the study of certain definite problems. In southern Indiana Mr. Herrick E. Wilson, under Mr. Springer's direction, spent a number of weeks quarrying for Niagaran echinoderms, particularly crinoids, in the vicinity of St. Paul where numerous outcrops of the Laurel limestone occur. The object of this work was to secure as many specimens as possible for comparisons of this peculiar fauna with those from European Silurian rocks. Not only was much material obtained by the quarrying operations, but all of the local collections of fossils were purchased for Mr. Springer, so that the Museum, which hitherto had practically no fossils from the Laurel limestone, is now in possession of a splendid general collection of fossils from this particular formation.

The second area of exploration was in west Tennessee along the Tennessee River, where Mr. W. F. Pate spent some weeks in searching for the peculiar crinoidal bulb, Camarocrinus, and the associated crinoid, Scyphocrinus, both of which Mr. Springer has proved to belong to the same organism. Mr. Pate was successful in finding several localities where excellent specimens of the Camarocrinus and Scyphocrinus were associated. Much material was secured and the specimens will be used in the preparation of Mr. Springer's monograph upon this group of crinoids.

GEOLOGICAL WORK IN PENNSYLVANIA AND VIRGINIA.

By arrangement with the United States Geological Survey, Dr. Edgar T. Wherry, of the National Museum, continued his studies of the geology of the Reading quadrangle in eastern Pennsylvania for a month during the summer of 1915. He completed the areal mapping of the Cambrian and Ordovician rocks of the region, and has transmitted to the Survey the manuscript of a report upon his work. He also mapped Cambrian and Triassic formations on

the Quakertown and Doylestown quadrangles, which lie to the east of the Reading.

A brief visit was made to a newly discovered cave near Lurich, Va., where the cave marble was reported to be of economic importance. This view proved to be unjustified, but some unusual stalactitic formations were found, two specimens of which were obtained for the Museum collections.

EXPEDITION TO BORNEO AND CELEBES.

As the result of zoological explorations carried on by Mr. H. C. Raven in Celebes, through the generosity of Dr. W. L. Abbott, the Museum has received 464 mammals, 870 birds, 50 reptiles, and some miscellaneous specimens. The mammals and birds are of great value as the first adequate representation of a fauna that has particular interest in connection with previous work in other parts of the Malay Archipelago. Early in the summer of 1915 Mr. Raven returned to America and spent several months on vacation and in preparing for further explorations in Celebes and other parts of the East Indies. Dr. Abbott has offered his continued support to this work. Mr. Raven left Washington for the East by way of Japan and Singapore, about the middle of October. Two months later he reported from Buitenzorg, Java, that he was making good progress toward the collecting ground.

EXPLORATIONS IN CHINA AND MANCHURIA.

Zoological explorations, mentioned in previous reports, have been continued in China and Manchuria by Mr. Sowerby through the generosity of a friend of the Institution who desires to remain unknown. During July, August, and September, he made an expedition to the lower reaches of the Sungari River and the I-mien-po district in north Manchuria, where he succeeded in collecting some interesting specimens of mammals, birds, and fishes to be forwarded to the Institution.

EXPLORATIONS IN EASTERN SIBERIA.

In the summer of 1915 Mr. Copley Amory, jr., returned from the northeast coast of Siberia, where for about a year he had been gathering zoological material in connection with a party under Capt. John Koren. As his part of the results of the expedition Mr. Amory turned over to the National Museum 365 mammals, 264 birds, and various miscellaneous specimens principally of plants, fish, and birds' eggs. Most of this material was prepared by Mr. Amory himself, though various members of the expedition contributed to the collections of both mammals and birds. Among the mammals, about

25 wild species are represented and are of interest for comparing the Alaskan species with their nearest Asiatic relatives.

EXPEDITION TO ST. THOMAS, DANISH WEST INDIES.

Mr. C. R. Shoemaker, of the division of marine invertebrates in the National Museum, spent the two months from the middle of June to the middle of August, 1915, in the Danish West Indies, under the auspices of the Carnegie Institution of Washington, D. C., securing collections of corals and other marine invertebrates. This expedition has enriched the collections of the National Museum by about 5,000 specimens, which it is hoped will throw considerable light on the correlation of these islands in the West Indian complex.

The collecting was done in the open water, bays, and channels at St. Thomas, St. John, and St. James. The deeper waters were explored by means of dredging from a motor boat, while native divers, working from the heavy West Indian row boats, were used for collecting in the shallow waters. In addition to this, much shore collecting was done. Owing to the very strong and constant trade wind, work on exposed reefs was in many cases made impossible by the heavy surf. Collecting in the protected bays, however, was most successful, as a great variety of bottom was to be found in many of them.

While the chief aim of the expedition was to secure as complete a representation of the coral fauna as possible—and this aim met with considerable success—fine collections of other marine invertebrates were also obtained, including protozoa, sponges, hydroids, medusæ, alcyonarians, anemones, bryozoans, starfish, sea urchins, holothurians, annelids, crustaceans, mollusks, and ascidians. Collections were also made on land whenever opportunities offered, including insects, mollusks, reptiles, and batrachians.

CACTUS INVESTIGATIONS IN BRAZIL AND ARGENTINA.

Dr. J. N. Rose, associate in Botany, United States National Museum (at present connected with the Carnegie Institution of Washington in the preparation of a monograph of the Cactaceæ of America), accompanied by Mr. Paul G. Russell, of the United States National Museum, continued the botanical exploration of South America during the summer of 1915, spending over five months in travel and field work in Brazil and Argentina.

In addition to the good-sized collections of cactuses, consisting of living, herbarium, and formalin specimens, moderately large collections of insects, shells, diatoms, and other natural-history specimens were obtained. In all about 8,000 herbarium specimens were obtained and over 90 cases, large and small, of living plants were sent

back to the United States. The living collection is now on exhibition at the New York Botanical Garden.

Bahia, Brazil, was the first place visited, which city served as a base for collecting trips into the interior of the State of Bahia. One of these was to the town of Joazeiro, located about 300 miles north-northwest of Bahia, and lying in a typical cactus desert, although this region is traversed by the large Rio Sao Francisco. Notwithstanding the fact that this stream is full the entire year, little or no attempt is being made to use the water for irrigation purposes. The country is of that type known as "catinga," and resembles in a remarkable way the deserts of the West Indies; indeed, the genera of plants are in many cases the same, though the species are distinct. Here was seen the "carnuba," or wax palm, from which is obtained the wax utilized in making records for phonographs. Near Joazeiro is the Horto Florestal, or "forest garden," a Government experiment station in charge of Dr. Leo Zehntner, who rendered great assistance in the study and collection of the cactuses of the region.

After making short stops at various stations in returning to Bahia, a trip was made to Machado Portella, a small town about 175 miles west and a little south of Bahia, the terminus of a little narrow-gauge railway. This is also a semiarid region and proved exceedingly interesting botanically. The next side trip was to Toca da Onca, still farther south, on the edge of a thick tropical forest and in a region much more humid than the northern part of the State.

About six weeks were then spent in beautiful Rio de Janeiro and vicinity. Here, even in the city itself, a botanist finds a great deal to interest him, for the trees are covered with epiphytic cactuses, mostly of the genus Rhipsalis, and within the city itself rises the picturesque Corcovado, a thickly wooded mountain on whose slopes are found many rare ferns and tree-inhabiting cactuses. The Jardin Botanico in this city is one of the finest in the world. Over 200 species of palms from all parts of the tropics are here grown in the open, besides many other rare tropical plants. In another section of the city, in a fine large park called the Quinta Boa Vista, is the Museo Nacional, where a number of rare cactuses were found in the herbarium.

From Rio de Janeiro an ascent of Itatiaya, the highest mountain in Brazil, was made, and on the very top, 10,000 feet above the sea, was found a small cactus with beautiful rose-colored flowers. Excursions were also made to Cabo Frio, to Ilha Grande, and to the islands in the Bay of Rio de Janeiro. A few days were spent in the Organ Mountains, near Petropolis, the summer home of the wealthiest classes of Rio de Janeiro. This range of mountains merits a more thorough biological exploration than has been hitherto undertaken.

Proceeding southward, a day was spent at Santos, Brazil, the world's greatest coffee center. Buenos Aires was visited next, although but little time was spent in the city. Several visits were made to the fine suburb of La Plata, where resides Dr. Carlos Spegazzini, the leading authority on Argentine cactuses.

From Buenos Aires a trip was taken across Argentina to Mendoza, a city situated near the foot of the Andes, in a region favorable to the growth of succulent plants. From there a short excursion was made to Portrerillos, Argentina, on the railway which leads to Valparaiso, Chile. Many very interesting plants were found in both these places.

In the city of Cordova, Argentina, northwest of Buenos Aires, the cactus collection of Dr. Frederick Kurtz was found to contain some rare types, which were very kindly submitted for examination and study. In this vicinity, as well as in the neighboring town of Cosquin, many cactuses were collected on the semiarid peneplain.

FOG-CLEARING INVESTIGATIONS.

Aided by a grant of $2,000 from the Smithsonian Institution and a grant from the Research Corporation, a committee of electrical engineering experts, under the general direction of Mr. F. G. Cottrell, continued during 1915 the investigations begun at San Francisco by the University of California, in cooperation with the United States Lighthouse Service, relative to the clearing of fog by means of electrical precipitation. In a preliminary report read at the first meeting of the committee, Prof. Ryan, of Stanford University, says:

> Science has established the fact that all dust and fog particles in the open atmosphere are electrified and subject to dispersion or precipitation. It is apparent, therefore, that a source of very high direct voltage, with facilities for control and application, may be of inestimable value in certain quarters and seasons for clearing fog away from a street, from along a passenger railway, from around the landing stages of a ferry, or, possibly, about or in advance of a ship under headway at sea.

The clearing of fog differs from the treatment of smoke and fumes in several respects, principally in that the smoke particles must be actually deposited on the electrodes to bring about the desired effect, whereas in treating fog it is only necessary to cause coalescence of the minute particles into larger ones to give much greater transparency, even disregarding the more rapid settling of the larger drops. However, other difficulties are to be expected in the problem of clearing fog, such as the conditions arising from the continual immersion in the wet atmosphere. What is chiefly needed for an intelligent conception of the problem is actual first-hand experience in handling these and other unusual conditions.

The most striking features of the apparatus used in these experiments are the Thordarson 350,000 to 1,000,000 volt transformers, which I saw while visiting the San Francisco Exposition.

A great deal was learned during the year about the electrical technique of the problem, and although days of suitable fog conditions were extremely scarce, on the rare occasions of actual trial very perceptible clearing for a short distance around the high-tension wires was obtained as the fog swept past.

EXPLORATIONS OF ANCIENT MAYA CITIES IN GUATEMALA AND HONDURAS.

Through the courtesy of the Carnegie Institution of Washington, the Smithsonian Institution has been enabled to participate in some very interesting explorations in Central America. Prof. W. H. Holmes, head curator of anthropology in the National Museum, gives the following general account of his work in that country:

> In February, 1916, owing to a generous grant of funds by the Smithsonian Institution, the writer had the good fortune to become a member of the Car-

negie Institution's archeological expedition to Central America under the able direction of Sylvanus G. Morley. The work of exploring and studying in detail the remarkable remains of the ancient Mayan culture was vigorously carried forward. An especial object of the expedition was the discovery of additional inscriptions embodying glyphic dates, for it is the dates, now read with facility, which furnish the skeleton of Maya history.

Among the ancient cities visited while the writer was associated with the expedition were Antigua, the ancient Spanish capital of the kingdom of Guatemala, built on the site of a prehistoric city; the extensive ruins of the ancient city of Iximche, near the site occupied to-day by the capital of Guatemala, Guatemala City; the ruined city of Quirigua in eastern Guatemala, the subject of much scientific interest during recent years; and the ruins of Copan, in Honduras, perhaps the most remarkable of all the American monuments of antiquity.

Especial attention was given by the writer to the collection of data and drawings to be utilized in preparing panoramic views of the several cities visited, and every effort was made to obtain information regarding the technical methods employed by the ancient builders. The quarries from which the stone was obtained were too deeply buried in tropical vegetation to yield up their story without extensive excavation and the methods employed in dressing and carving the stone remain in large part undetermined. Certain chipped and ground stone implements that could have served in dressing the stones used in building were found in numbers, but the story of the carving, especially of the very deep carving of the monuments of Copan, remains unrevealed. Although it is thought that stone tools may have been equal to the great task, it is believed by some that without bronze the work could not have been done. There are, however, no traces of the use of bronze by the Central Americans.

The monuments are on a grand scale and great skill and excellent taste are manifest in their embellishment, the whole giving evidence of a state of culture advancement unsurpassed in any other part of aboriginal America.

STUDY OF NOCTURNAL RADIATION.

Several grants from the Hodgkins fund have been made to Prof. Anders Ångström during the past few years to enable him to carry on researches on the radiation of the atmosphere, particularly nocturnal radiation. The results of observations made by him in Algeria in 1912 and in California in 1913 were embodied in a pamphlet published by the Institution in 1915. In this pamphlet he summarizes his work as follows:

The main results and conclusions that will be found in this paper are the following. They relate to the radiation emitted by the atmosphere to a radiating surface at a lower altitude, and to the loss of heat of a surface by radiation toward space and toward the atmosphere at higher altitudes.

I. The variations of the total temperature radiation of the atmosphere are at low altitudes (less than 4,500 m.) principally caused by variations in temperature and humidity.

II. The total radiation received from the atmosphere is very nearly proportional to the fourth power of the temperature at the place of observation.

III. The radiation is dependent on the humidity in such a way that an increase in the water-vapor content of the atmosphere will increase its radiation. The dependence of the radiation on the water content has been expressed by an exponential law.

IV. An increase in the water-vapor pressure will cause a decrease in the effective radiation from the earth to every point of the sky. The fractional decrease is much larger for large zenith angles than for small ones.

V. The total radiation which would be received from a perfectly dry atmosphere would be about $0.28 \frac{\text{cal.}}{\text{cm.}^2\text{min.}}$ with a temperature of 20° C. at the place of observation.

VI. The radiation of the upper, dry atmosphere would be about 50 per cent of that of a black body at the temperature of the place of observation.

VII. There is no evidence of maxima or minima of atmospheric radiation during the night that can not be explained by the influence of temperature and humidity conditions.

VIII. There are indications that the radiation during the daytime is subject to the same laws that hold for the radiation during the nighttime.

IX. An increase in altitude causes a decrease or an increase in the value of the effective radiation of a blackened body toward the sky, dependent upon the value of the temperature gradient and of the humidity gradient of the atmosphere. At about 3,000 meters altitude of the radiating body the effective radiation generally has a maximum. An increase of the humidity or a decrease of the temperature gradient of the atmosphere tends to shift this maximum to higher altitudes.

X. The effect of clouds is very variable. Low and dense cloud banks cut down the outgoing effective radiation of a blackened surface to about 0.015 calorie per cm.^{2} per minute; in the case of high and thin clouds the radiation is reduced by only 10 to 20 per cent.

XI. The effect of haze upon the effective radiation to the sky is almost inappreciable when no clouds or real fog are formed. Observations in Algeria in 1912 and in California in 1913 show that the great atmospheric disturbance caused by the eruption of Mount Katmai in Alaska, in the former year, can only have reduced the nocturnal radiation by less than 3.0 per cent.

XII. Conclusions are drawn in regard to the radiation from large water surfaces, and the probability is indicated that this radiation is almost constant at different temperatures, and consequently in different latitudes also.

Another grant was made to Prof. Ångström in October, 1915, for a study of nocturnal radiation in the far north during the long Arctic night. Concerning this study he wrote to the Institution on February 16, 1916, as follows:

Through this grant I have been able to make observations on nocturnal radiation during the Arctic night in the north of Sweden, at a place named Abisko, at about 68° 30′ latitude. The observations were extended during about a month (Jan. 1–26) and were obtained under various atmospheric conditions. One night observations were taken at a temperature of —30° C. (—20° F.), when consequently the absolute humidity must have been very low. In general, these observations confirm the views expressed in my paper[1] in regard to the influence of temperature and humidity upon the nocturnal radiation and the radiation of the atmosphere.

In connection with the named measurements observations were also made on the cooling of snow surfaces under the temperature of the surrounding air as a consequence of nocturnal radiation. As was to be expected, a linear relation was found to exist between the radiation and the named temperature difference.

[1] Smithsonian Misc. Coll., Vol. 65, No. 3, 1915.

I hope in the near future to get an opportunity to extend these important observations on the connection existing between radiation and the cooling of various materials existing on the earth's surface. The question is one of scientific as well as of practical agricultural interest.

HARRIMAN TRUST FUND.

Dr. C. Hart Merriam, research associate of the Institution, aided by the income of a trust fund established for the purpose by Mrs. E. H. Harriman, has continued his zoological investigations, particularly the study of the big bears of North America.

RESEARCH CORPORATION.

The Research Corporation was established in 1912 under the New York State laws with the Secretary of the Smithsonian Institution as one of the directors and a member of the executive committee. The primary object of the organization was to develop certain patents described in previous reports which had been offered to the Institution by Dr. F. G. Cottrell but which could not be administered directly by the Institution. Other inventions and patents have since been acquired by the corporation, and through royalties from the installation and utilization of these patents a considerable fund has been created and the income therefrom will be devoted to the advancement of technical and scientific investigation and experimentation through the agency of the Smithsonian Institution and such other scientific and educational institutions and societies as may be selected by the directors.

The Cottrell patents relate to the precipitation of dust, smoke, and chemical fumes by the use of electrical currents. Successful commercial installations have already been made on the following fumes:

(*a*) Silver fumes from electrolytic slimes of copper refinery; (*b*) tin fumes from detinning process residues; (*c*) hydrochloric acid fumes from cleaning vats in electrogalvanizing plant; (*d*) tin and zinc fumes from waste metal recovery plant; (*e*) "low bleach" from electrolytic plant; (*f*) sulphuric acid mist from contact acid plant; (*g*) lead fumes from copper converters; (*h*) fumes from roasting of zinc ores; and (*i*) dust from buffing wheels and from machines for powdering slate.

NATIONAL RESEARCH COUNCIL.

At its annual meeting in Washington in April, 1916, the National Academy of Sciences voted unanimously to offer its services to the President of the United States in the interest of national preparedness, and it was suggested that the academy "might advantageously

organize the scientific resources of educational and research institutions in the interest of national security and welfare." The President accepted the offer and requested the academy to proceed with the organization. An organizing committee was accordingly appointed, and on June 19 the council of the academy, acting upon recommendations of that committee, voted—

That there be formed a National Research Council whose purpose shall be to bring into cooperation existing governmental, educational, industrial, and other research organizations with the object of encouraging the investigation of natural phenomena, the increased use of scientific research in the development of American industries, the employment of scientific methods in strengthening the national defense, and such other applications of science as will promote the national security and welfare.

That the council be composed of leading American investigators and engineers, representing the Army, Navy, Smithsonian Institution, and various scientific bureaus of the Government; educational institutions and research endowments; and the research divisions of industrial and manufacturing establishments.

After the close of the fiscal year the National Research Council was fully organized, the President of the United States appointing the representatives of the Government and authorizing the appointment of other members by the president of the National Academy of Sciences.

OFFICERS AND EXECUTIVE COMMITTEE.

Chairman, George E. Hale; vice chairmen, Charles D. Walcott and Gano Dunn; secretary, Cary T. Hutchinson; executive committee, John J. Carty (chairman), William H. Welch (ex officio), George E. Hale (ex officio), Edwin G. Conklin, Gano Dunn, Arthur A. Noyes, Raymond Pearl, Michael I. Pupin, S. W. Stratton, V. C. Vaughan (others to be appointed).

MEMBERS OF NATIONAL RESEARCH COUNCIL.

Dr. L. H. Baekeland, Yonkers, N. Y.

Dr. Marston T. Bogert, professor of organic chemistry, Columbia University.

Dr. John A. Brashear, Allegheny, Pa.

Dr. John J. Carty, chief engineer, American Telephone & Telegraph Co.

Dr. Russell H. Chittenden, director, Sheffield Scientific School, Yale University.

Dr. Edwin G. Conklin, professor of zoology, Princeton University.

Dr. John M. Coulter, professor of botany, University of Chicago.

Brigadier General William Crozier, Chief of Ordnance, U. S. Army.

Mr. Gano Dunn, president The J. G. White Engineering Corporation.

Dr. Simon Flexner, director, Rockefeller Medical Institute.

Major General William Crawford Gorgas, Surgeon General, U. S. Army.

Dr. W. F. M. Goss, dean of engineering, University of Illinois.

Dr. George E. Hale, director, Mount Wilson Solar Observatory.

Mr. Clemens Herschel, president American Society of Civil Engineers.

Prof. William H. Holmes, head curator of anthropology, United States National Museum.

Dr. W. W. Keen, president American Philosophical Society.

Mr. Van H. Manning, Director U. S. Bureau of Mines.

Prof. Charles F. Marvin, Chief United States Weather Bureau.

Prof. A. A. Michelson, director, Ryerson Physical Laboratory, University of Chicago.

Dr. Robert A. Millikan, professor of physics, University of Chicago.

Dr. Arthur A. Noyes, director, research laboratory of physical chemistry, Massachusetts Institute of Technology.

Dr. Raymond Pearl, director, Maine Agricultural Experiment Station.

Prof. E. C. Pickering, director, Harvard College Observatory.

Dr. Michael I. Pupin, professor of electro-mechanics, Columbia University.

Mr. Charles F. Rand, president United Engineering Society.

Prof. Theodore W. Richards, director of the Wolcott Gibbs Memorial Laboratory, Harvard University.

Mr. C. E. Skinner, director, research laboratory, Westinghouse Electric & Manufacturing Co.

Lieutenant Colonel George O. Squier, Chief of Aviation, U. S. Army.

Dr. S. W. Stratton, Director U. S. Bureau of Standards.

Mr. Ambrose Swasey, Cleveland, Ohio.

Rear Admiral David W. Taylor, Chief Constructor U. S. Navy.

Dr. Elihu Thomson, Swampscott, Mass.

Dr. C. R. Van Hise, president of the American Association for the Advancement of Science.

Dr. Victor Clarence Vaughan, director, medical research laboratory, University of Michigan.

Dr. Charles D. Walcott, Secretary of the Smithsonian Institution.

Dr. William H. Welch, president of the National Academy of Sciences.

Dr. W. R. Whitney, director of the research laboratory, General Electric Co.

The council will be gradually enlarged by the addition of new members who are to serve as chairmen of important committees or who are otherwise to engage in some special work.

To carry out the work of the council committees are being appointed, including (*a*) committee on rules and procedure; (*b*) committee on publication; (*c*) committee on research in educational institutions to consider general plans for the promotion of research in educational institutions and to arrange for local committees in each institution; (*d*) committee on promotion of industrial research with functions in the field somewhat similar to those of the preceding committee; (*e*) committee on a national census of research to prepare a national census of equipment for research, of the men engaged in it, and of lines of investigation pursued in cooperating Government bureaus, educational institutions, research foundations, and industrial research laboratories. It has also been decided to form joint committees in various branches of science in cooperation with the corresponding national scientific societies.

THE LANGLEY AERODYNAMICAL LABORATORY.

In view of the organization of the National Advisory Committee for Aeronautics, provided for by act of Congress approved March 3, 1915, it has appeared unnecessary at present to proceed further toward the permanent establishment of the proposed Langley labora-

tory. As secretary of the Smithsonian Institution, I was appointed a member of the National Advisory Committee and elected chairman of its executive committee, and in this connection I have been able to cooperate toward the solution of many important problems pertaining to the science and art of aviation. One of the chief advantages already being realized by the establishment of the advisory committee is a closer cooperation between the Army and Navy and other Federal departments and coordination of work in the general advancement of aviation. The Institution published during the year two pamphlets on aeronautics, one, a series of reports on wind tunnel experiments, and the other on "Dynamical stability of aeroplanes," both of them by J. C. Hunsaker and associates.

PUBLICATIONS.

The publications of the Institution proper include three series: Smithsonian Contributions to Knowledge; Smithsonian Miscellaneous Collections; and Smithsonian Annual Reports. Under the direction of the Institution there are also issued the Annual Reports, Proceedings, and Bulletins of the United States National Museum, including the Contributions from the National Herbarium; Annual Reports and Bulletins of the Bureau of American Ethnology; and the Annals of the Astrophysical Observatory. All of these series except the "Contributions" and "Collections" are printed through annual Congressional allotments. In all of these series there was published during the year a total of 8,498 pages and 623 plates of illustrations.

Smithsonian Contributions to Knowledge.—This series is intended to show results of original research constituting important contributions to knowledge. One memoir of the series was in press at the close of the year giving the results of an extended study on the comparative histology of the femur.

Smithsonian Miscellaneous Collections.—Twenty-two papers, forming parts of five volumes of this series, were issued, among them three papers on Cambrian geology by your secretary. In this series the annual exploration pamphlet was issued, giving brief accounts of the explorations and field work of the Institution in geology, biology, and anthropology, covering every continent on the globe, and illustrated by 141 photographs taken in the field by the scientists themselves. The Smithsonian Physical Tables, which together with the Mathematical and Geographical Tables have become standard works of reference in educational and research institutions, are published in this series. The sixth revised edition of the Physical Tables, issued during the preceding year, was quickly exhausted, making it necessary to print additional copies. Still another edition is now in press, indicating the constant demand for this work.

Smithsonian report.—The complete volume of the 1914 report was received from the printer and distributed at the beginning of the year. Material for the 1915 report was sent to press in December, and was completed just before the fiscal year closed. In the general appendix are 22 papers showing recent progress in various branches of science, including "The utilization of solar energy," "Evidences of primitive life," by your secretary, "Heredity," "Linguistic areas in Europe," and "Recent developments in telephony and telegraphy." The custom of printing special editions in pamphlet form of papers in the general appendix has proved of great advantage; in several cases there has been a demand for a very large number of copies, which was especially noticeable in connection with an article on "The value of birds to man" in the 1913 report.

Special publications.—Opinion 67 of the Opinions of the International Commission on Zoological Nomenclature was issued as a special publication. A special paper by Chester G. Gilbert of the National Museum, on "Sources of nitrogen compounds in the United States" attracted considerable attention. Among other conclusions, he states:

The evolution of a practicable process for the oxidation of by-product ammonia to render present resources available, with the development of an atmospheric nitrogen fixation output by the Cyanamide process carefully timed to meet growing demands following a reduction in the retail price of nitrogenous fertilizer, would appear to be the desirable governmental procedure as being the one least liable to disastrous consequences.

National Museum publications.—The National Museum issued an annual report, 2 volumes of the proceedings, 52 separate papers forming parts of these and other volumes, and 4 bulletins.

Bureau of Ethnology publications.—The Bureau of American Ethnology published 2 annual reports, separates of 4 accompanying papers in these reports, and 2 bulletins.

Reports of historical and patriotic societies.—The annual reports of the American Historical Association and the National Society of the Daughters of the American Revolution were submitted to the Institution and communicated to Congress in accordance with the charters of these organizations.

Allotments for printing.—Most of the allotment to the Institution and its branches for printing was used during the year, though it was impracticable to complete a large amount of material in press at the close of the year in the National Museum and Bureau of American Ethnology series.

The allotments for the year ending June 30, 1917, are as follows:

For the Smithsonian Institution: For printing and binding the annual reports of the Board of Regents, with general appendices, the editions of which shall not exceed 10,000 copies	$10,000

For the annual reports of the National Museum, with general appendices, and for printing labels and blanks, and for the Bulletins and Proceedings of the National Museum, the editions of which shall not exceed 4,000 copies, and binding, in half morocco or material not more expensive, scientific books, and pamphlets presented to or acquired by the National Museum library	$37,500
For the annual reports and Bulletins of the Bureau of American Ethnology and for miscellaneous printing and binding for the bureau	21,000
For miscellaneous printing and binding:	
International Exchanges	200
International Catalogue of Scientific Literature	100
National Zoological Park	200
Astrophysical Observatory	200
For the annual report of the American Historical Association	7,000
Total	76,200

Committee on printing and publication.—All manuscripts submitted for publication by the Institution or its branches have, as usual, been referred to the Smithsonian advisory committee on printing and publication. During the year 18 meetings were held and 96 manuscripts examined and passed upon. The personnel of the committee was as follows: Dr. Leonhard Stejneger, head curator of biology, National Museum, acting chairman; Dr. C. G. Abbot, director of the Astrophysical Observatory; Dr. Frank Baker, superintendent of the National Zoological Park; Mr. A. Howard Clark, editor of the Smithsonian Institution, secretary of the committee; Mr. F. W. Hodge, ethnologist in charge of the Bureau of American ethnology; and Dr. George P. Merrill, head curator of geology, United States National Museum.

LIBRARY.

The accumulation of a scientific library has always been an important phase of the Institution's work in the "increase and diffusion of knowledge," and the collection has increased in size from year to year until at present it numbers well over half a million titles. The accessions of the year aggregated about 13,000 books and pamphlets.

The main Smithsonian library is assembled in the Library of Congress and is known as the Smithsonian deposit. In addition the Institution maintains the Smithsonian office library, the National Museum library, the library of the Bureau of American Ethnology, the Astrophysical Observatory library, and the National Zoological Park library, besides some 35 specialized sectional libraries maintained in various offices for the use of the scientific staff of the Institution and its branches. The Smithsonian office library contains a collection of books relating to art, the employees' library, and an extensive aeronautical library. This collection of aeronautical works has been notably increased by additional gifts from Dr. Alexander

Graham Bell, consisting of 33 books and 37 portfolios of periodicals, and by a number of reference works from the library of Major Baden-Powell.

The National Museum library received 4,840 accessions, among them 207 titles contributed by Dr. William Healey Dall to his collection of works relating to mollusks; and the scientific library of Dr. Theodore Nicholas Gill, numbering about 3,000 volumes, presented to the Institution by his brother, Mr. Herbert A. Gill, which is a valuable addition to the natural history series, especially in ichthyology.

INTERNATIONAL CONGRESSES AND EXPOSITIONS.

SECOND PAN AMERICAN SCIENTIFIC CONGRESS.

The Second Pan American Scientific Congress, which held its sessions in Washington from December 27, 1915, to January 8, 1916, was the fifth of a series of scientific congresses, the first three of which included only the Latin American countries. At the first strictly Pan American Congress, held in Peru in 1908, in which the United States was invited to participate, it was unanimously voted to hold the next meeting in Washington. The congress held its inaugural session at 10 a. m., December 27, at Memorial Continental Hall, and business sessions and social affairs were arranged for every day thereafter until January 8. The following are the sections into which the congress was divided:

I. Anthropology.
II. Astronomy, Meteorology, and Seismology.
III. Conservation of Natural Resources, Agriculture, Irrigation, and Forestry.
IV. Education.
V. Engineering.
VI. International Law, Public Law, and Jurisprudence.
VII. Mining and Metallurgy, Economic Geology, and Applied Chemistry.
VIII. Public Health and Medical Science.
IX. Transportation, Commerce, Finance, and Taxation.

At the meetings of these sections a great number of papers of scientific and economic importance were read.

The Institution proper was represented in the congress by your secretary and Prof. W. H. Holmes, head curator of anthropology, United States National Museum, as delegates. Of the branches of the Institution, the Bureau of American Ethnology was represented by the ethnologist in charge, Mr. F. W. Hodge, and Dr. J. W. Fewkes, delegates; and the Astrophysical Observatory by Dr. C. G. Abbot, delegate, and Mr. F. E. Fowle, alternate. A reception was held for the Latin American delegates by the Board of Regents and

the Secretary of the Institution in the new building of the National Museum on the evening of December 29.

This highly successful and important congress was attended by approximately 100 official delegates from the 21 American Republics, and 60 by special invitation, or representing societies or universities. The United States was represented by approximately 1,000 unofficial delegates or members.

NINETEENTH INTERNATIONAL CONGRESS OF AMERICANISTS.

The Nineteenth International Congress of Americanists, which was to have been held at Washington on the invitation of the Smithsonian Institution in October, 1914, was postponed on account of the war in Europe until a more favorable time for an international gathering. When it became evident that a fully attended meeting would be out of the question in the near future, it was decided to hold the congress in affiliation with the section of anthropology of the Second Pan American Scientific Congress and jointly with the American Anthropological Association, the American Folk-Lore Society, the American Historical Association, and the Archaeological Institute of America. In consequence the date of the meeting was definitely fixed for December 27–31, 1915.

Mr. John W. Foster, ex-Secretary of State, former minister to Mexico and Russia, ex-president of the Washington Society of the Archaeological Institute, etc., served as president of the congress. The honorary presidents were the Secretary of the Smithsonian Institution; Mr. Clarence B. Moore, of Philadelphia; and Prof. William H. Holmes, of the National Museum. Mr. Clarence F. Norment, of Washington, served as treasurer, and Dr. Aleš Hrdlička, of the National Museum, as secretary of the Congress. There was a long list of honorary vice presidents, a general (honorary) committee, associate foreign secretaries, and an organizing committee (with the Secretary of the Smithsonian Institution as chairman).

Official representatives of foreign Governments were in attendance from Austria, Chile, Cuba, Germany, Great Britain, Greece, Guatemala, Nicaragua, Peru, Russia, Sweden, and Uruguay, and about 100 official delegates from various learned societies and universities in the United States and foreign countries.

The headquarters of the congress were at the National Museum, and most of the sessions were held there.

Nearly 100 papers relating to the study of somatology, archeology, ethnology, folklore, history, and linguistics were read at the sessions of the congress, among them papers by several members of the staff of the Bureau of American Ethnology and of the National Museum.

PANAMA-PACIFIC INTERNATIONAL EXPOSITION.

Only a very small allotment was allowed the Smithsonian Institution and its branches from the congressional appropriation for Government exhibits at San Francisco in 1915. It was possible, however, to make a small display showing in a general way the scope and activities of the Institution, and an ethnological exhibit illustrating the characteristics and culture status of typical primitive peoples. The exhibits were located in the Liberal Arts Palace, covering a floor space of about 6,000 square feet.

The exhibit of the Institution proper consisted of a series of photographs of its founder, James Smithson, the four secretaries, pictures of the building and departments, and a complete set of its publications. There was also displayed an exact reproduction of the Langley experimental steam flying machine which performed the epoch-making flights over the Potomac River, May 6, 1896, together with photographs taken at the time. Langley's success as a pioneer in aviation was commemorated on the Column of Progress at the exposition (pl. 1) by a tablet with the following inscription:

> To commemorate science's gift of aviation to the world through Samuel Pierpont Langley, an American.

The principal exhibit by the National Museum dealt with ethnology, or the scientific study of the races of men, their origin, distribution, relations, and culture. It included four family lay-figure groups, the Eskimo of Alaska, the Dyak of the East Indies, the Zulu-Kaffir of South Africa, and the Carib of South America; also village groups in miniature illustrating the houses and house life of various peoples, together with cases of specimens relating to the primitive arts and industries.

The remaining departments or branches of the Institution, including the International Exchange Service, the Bureau of American Ethnology, the Astrophysical Observatory, the Zoological Park, the Hodgkins fund, the Aerodynamical Laboratory, and the Regional Bureau of the International Catalogue of Scientific Literature, were represented by charts, photographs, maps, instruments, and publications illustrative of their various functions.

Mr. W. de C. Ravenel, administrative assistant of the United States National Museum and secretary to the exposition board, acted as the representative of the Smithsonian Institution and its branches, with the assistance of Dr. Walter Hough, curator of ethnology, United States National Museum.

The exhibits were enumerated in detail in a descriptive catalogue of 120 pages.

The family groups illustrated the most effective museum method of presenting ethnological material. The catalogue describes the groups as follows:

The Eskimo family group comprises seven life-size figures clad in the native costumes and colored according to life, engaged in the usual summer vocations and amusements. At the left a woman is cooking meat in a primitive pottery vessel, and another woman is putting dried fish in the storehouse. In the background a man with a sinew-backed bow is watching a youth practicing with his sling. On the right another man is seated on the ground carving a wooden dish with a curved knife, and two little girls are playing with their native toys. The structure in the back of the case is a representation of the storehouse commonly used by the western Eskimo. The dwelling groups show the houses to be dome-shaped, made of earth piled over a cobwork of timbers erected in an excavation in the ground. In the summer a passageway gives entrance, but in the winter a tunnel is built. A bench on which the people sleep runs around the wall on the inside of the house. The cooking within the dwelling is done in a pottery vessel suspended over a lamp.

The group representing the Zulu-Kaffir and Bantu tribes, which live in the semiarid southern extremity of the African continent, depicts the natives as physically strong and energetic and not so dark as the true negro. This race is superior in military and social organizations and compares favorably in the arts and industries with other African families. The group shows a section of a house with a doorway, a fireplace on which a woman is cooking mush, a woman dipping beer from a large pottery jar, a woman from the field with a hoe, a water carrier with a jar on her head, a man playing a marimba or xylophone, and a boy driving a goat. The natives are represented as they existed some years ago, before they were affected by contact with the white man. Other cases include models of the native African dwellings and examples of the handiwork of these people, an interesting feature of which is the primitive ironwork in which many African tribes were highly skilled.

The next group takes the exposition visitor from Africa across the Atlantic to northern South America, where dwells the Carib in the forested tropical interior of British Guiana. Some of the tribes of this great race have only recently been visited by white men. Here is to be seen a Carib warrior with his blowgun, a woman and a child squeezing cassava in a primitive lever press, another woman decorating a tree gourd with characteristic interlocking designs, and a child playing with a pet parrot. A hammock swung between two house posts represents the form of bed in general use in ancient as well as modern Latin America. Among the articles manufactured by these natives examples of ceremonial objects and articles of personal adornment are exhibited, including headdresses, earrings, belts, arm bands, necklaces, and capes.

A fourth family group represents the Dyaks of the island of Borneo. They are expert house and boat builders and skilled in the use of the blowgun. Rice, sago, tropical fruits, monkeys, wild pigs, and other game, yield them subsistence. The men are warlike, and are still, to some extent, head-hunters, their weapons being spears, short swords, and blowguns with poison-tipped darts. The Dyak family group is represented on the porch of a communal house, carrying on various occupations. A woman is pounding rice in a wooden mortar, while another is represented as bringing in a basket of rice on her back, a third is making a basket, a man armed with a bayoneted blowgun is approaching with a freshly killed monkey, and two children are shown playing cat's cradle, a popular native game.

The museum exhibits also included a series of objects illustrating the development of six kinds of implements and appliances of the arts—apparatus for fire making, the jackknife, the saw, the spindle, the shuttle, and the ax. Pictures of other exhibits in biology, geology, and anthropology in the National Museum were shown by a "stereomotorgraph" machine.

The Smithsonian Institution was awarded a grand prize, under the head of scientific investigation, for the collective exhibit by the Institution proper, the Bureau of American Ethnology, the Museum, the Astrophysical Observatory, and the Bureau of International Catalogue of Scientific Literature; a grand prize for the balloon pyrheliometer designed and exhibited by the Astrophysical Observatory; a gold medal for the "Group of elk" shown by the Museum; and a silver medal for investigations for the betterment of social and economic conditions. The balloon pyrheliometer, as its name implies, is an instrument for measuring the heat of the sun. It is carried aloft by a pair of rubber balloons until one of them bursts, when it gradually descends to the earth, supported by the other. Records have thus been obtained at heights of over 9 miles.

PANAMA-CALIFORNIA EXPOSITION AT SAN DIEGO.

Although no appropriation was made by Congress for exhibits at San Diego in 1915, it was possible for the Institution, through cooperation with the exposition authorities, to arrange an interesting exhibit of physical anthropology and one illustrating American aboriginal industries. These exhibits were described in my report of last year.

At the close of the San Francisco Exposition a number of the Smithsonian exhibits were transferred to San Diego, this fair having been extended over another year. These exhibits were located in the Science of Man Building, and included four large cases containing the family groups of natives from different quarters of the globe, as described above, and some cases containing specimens of their arts and industries, together with several small family dwelling groups.

NATIONAL MUSEUM.

The report of Assistant Secretary Rathbun, appended hereto, reviews in detail the operations of the National Museum. The total number of new specimens acquired was 243,733; about one-half pertained to the department of zoology, about one-third were botanical and paleontological, and the rest were additions to the anthropological and other collections. Among the ethnological additions of special interest may be noted a series of costumes, weapons, and utensils from British Guiana; many objects from Celebes,

Borneo, and the Philippines; and a large collection from aboriginal mounds and ruin sites in Utah. To the division of American history the additions included china and glassware and other objects once the property of General and Martha Washington. The memorials of Gen. Sherman, which had long been in the custody of the Museum, have now been presented by his son, Hon. P. Tecumseh Sherman, and the Cromwell collection of 20,000 domestic and foreign postage stamps, deposited some years ago, became the absolute property of the Museum on the death of Mr. Cromwell in September, 1915.

To the interesting collection of historical costumes there have been added costumed figures representing four hostesses of the White House, Mrs. James Monroe, Mrs. John Quincy Adams, Mrs. Abraham Lincoln, and Mrs. James R. McKee.

By the will of Dr. Shepard there was bequeathed an important collection of meteorites which had been in the possession of the Museum for a number of years.

In the department of biology the additions were representative of many parts of the world, including mammals, birds, and reptiles from Celebes and Borneo, collected through the long-continued generosity of Dr. W. L. Abbott; and like collections from Siam, Kashmir, northern China, and Manchuria. Part of the results of the Smithsonian biological survey of the Panama Canal Zone was a collection of about 18,000 fishes. The Carnegie Institution of Washington deposited some 8,000 botanical specimens gathered by Dr. J. N. Rose in Brazil and Argentina.

Mr. Rathbun enumerates many other interesting objects recently received, particularly those pertaining to the industrial arts, a department which has been very greatly developed since the removal of the natural history exhibits to the new building, yet the proper installation of series illustrating the many branches of the arts and industries is already seriously hindered through lack of space. It is in this department in particular that the Museum manifests one of its principal functions. The exhibits are so selected and so installed as to teach visitors how things are made and what they are made of, and not so much who makes the best articles or how they should be packed to meet the demands of trade. And yet while these collections first of all educate the public they also teach the manufacturer and therefore are of decided economic importance. One of the leading New England manufacturers not long since, while examining the exhibits in his own industrial line, remarked, "this helps business."

I can not too strongly urge the need of still greater advancement in this department of Smithsonian activities. The time is fast ap-

proaching when there should be constructed in the Smithsonian reservation another new building, a Museum of Industrial Arts. The collections are here and in many respects they surpass similar collections in Europe or elsewhere. The splendid new building in which the natural history collections are now so adequately housed has offered opportunity for the development of that department beyond the highest expectations. Like progress could be made with a Museum of Industrial Arts. European countries have such structures, one is needed here in Washington. It is an economic question. Commercial museums have their place for developing trade and commerce, and are of much value for such purpose, but the development of the artistic taste of the public through an educational Museum of Industrial Arts is of even greater importance. It would stimulate inventive skill and advance every art and every industry. The exhibits illustrating textile industry and mineral technology in particular are very complete, consisting of specimens of raw materials, machinery used in manufacture, and the finished products.

To the National Gallery of Art there has been added a collection of 82 drawings in pencil, pen, etc., by contemporary French artists, a gift from citizens of France to the people of the United States; also an oil painting of Abraham Lincoln, by Story, the gift of Mrs. E. H. Harriman. The paintings in the National Gallery collection are of much popular interest and of great artistic and intrinsic value, but they are crowded in temporary quarters in a building designed for purposes other than a gallery of art.

During the last year Mr. Freer made 535 additions to his collection, including 23 paintings and sculptures by American artists, and over 500 oriental objects consisting of paintings, pottery, bronzes, and jades. The entire collection now aggregates about 5,346 items.

The auditorium in the new building has been the meeting place of a number of scientific bodies and of international congresses; and in the foyer opportunity was offered for several special exhibitions.

In cooperating with schools and colleges there were distributed some 7,000 duplicate specimens of minerals, fossils, mollusks, and other objects, classified and labeled for teaching purposes.

The number of visitors to the new building averaged 1,012 on week days and 1,240 on Sundays.

BUREAU OF AMERICAN ETHNOLOGY.

The Bureau of American Ethnology is under the direct charge of Mr. F. W. Hodge, whose detailed report is appended hereto. The operations of the bureau include field work and special researches pertaining to the American Indians and the natives of Hawaii.

With the cooperation of the Museum of the American Indian, Heye Foundation, the Nacoochee mound in Georgia was excavated and

proved to have been used both for domicile and for burial purposes. In the mound were found a large number of smoking pipes and a great amount of broken pottery. In New Mexico, also in cooperation with the Museum of the American Indian, plans were made for excavating the historic pueblo of Hawikuh in the Zuñi Valley southwest of Zuñi pueblo. Among the most interesting field operations during the year were those by Dr. Fewkes in the Mesa Verde National Park, Colo., where he unearthed a type of structure architecturally different from any hitherto found in the Southwest. The excavation was carried on under the joint auspices of the bureau and the Department of the Interior, and the building, which Dr. Fewkes has named the Sun Temple, is described in a pamphlet published by that department. The Sun Temple is a large D-shaped structure, the longest wall of which measures 131 feet 7 inches. The walls are 2 to 5 feet in thickness and show structural qualities that compare favorably with any building of this type north of Mexico. Dr. Fewkes is of the opinion that though the building was used primarily as a place of worship, it was intended also for a place of refuge in case of attack.

In the Northwest, investigations were continued by Dr. Frachtenberg on the languages, history, and traditions of the various Indian tribes of Oregon and Washington. In connection with this work it is interesting to note that in revising some manuscript material Dr. Frachtenberg secured the assistance of the last surviving member of the Atfalati tribe of the Kalapuya Indians.

A number of special researches have been in progress during the year, among them research work by Dr. Franz Boas in connection with the completion of part 2 of the Handbook of American Indian Languages. Through the liberality of Mr. Homer E. Sargent, of Chicago, work has been well advanced on an extended study of the Salish dialects, as well as on a study of Salish basketry, which it is intended to describe in an illustrated memoir. Part 1 of the Handbook of American Antiquities by Prof. W. H. Holmes was in type at the close of the year, and the preparation of part 2 was well under way.

The study of Indian music by Miss Frances Densmore, which has attracted considerable attention among musicians, has been continued during the year, chiefly among the Mandan and Hidatsa Indians in North Dakota. A number of ceremonial and war songs were recorded phonographically and a new phase of the work was undertaken, consisting of testing the pitch discrimination of the Indians by means of tuning forks. There was in press at the close of the year a bulletin by Miss Densmore entitled "Teton Sioux music."

The publications of the bureau issued during the year comprise two annual reports with their accompanying papers, and two bulletins. In press or in preparation at the close of the year were three annual reports and five bulletins. The bureau library was enriched by the addition of 1,078 volumes, among them 20 volumes of Bibles and portions of the Bible in American Indian languages.

INTERNATIONAL EXCHANGES.

The total number of packages of governmental and other documents handled by the International Exchange Service during the year was 301,625, an increase of 25,869 over the previous year. This figure, however, still shows a decrease as compared with the total handled in 1914, owing to the suspension of shipments to 10 countries involved in the European war. Efforts have been made to resume shipments to certain of these countries, which have met with some degree of success in the case of Germany and Russia.

The Exchange Service has continued its policy of international helpfulness by assisting governmental and scientific establishments to procure publications especially desired both in this country and abroad. One instance showing the value of this policy may be cited. The Pan American division of the American Association for International Conciliation, of New York, wished to assemble a collection of several thousand volumes of North American origin for presentation to the Museo Social Argentino at Buenos Aires. Through the Exchange Service the matter was brought to the attention of the proper establishments and several hundred governmental and other publications were received for the proposed collection.

The number of sets of United States governmental documents sent through the Exchange Service to foreign countries has been reduced from 92 to 91, owing to the discontinuance of shipments to the government of Bombay at the request of that government.

NATIONAL ZOOLOGICAL PARK.

The National Zoological Park is becoming each year a greater and greater attraction to the public, and as its collections increase so does its value become of more importance as a source of information to the zoologist in his study of animal life.

There is now in the park a total of 1,383 individual animals, representing 360 species, as shown by the detailed census in the report of the superintendent.

Among the recent accessions may be mentioned a pair of young lions, a pair of Siberian tigers, a great red kangaroo, several monkeys, and a number of interesting birds, but the newly acquired ani-

mal that seems most popular is a male chimpanzee, about 4½ years old, from the forests of French Congo.

The number of visitors during the past year was 1,157,110, as compared with 794,530 in the year preceding. This included 161 schools, classes, etc., numbering 8,679 individuals.

Recent improvements include the construction of a hospital and laboratory building and the grading of some ridges and gullies to secure additional building sites and paddocks for the deer and other large animals.

As mentioned in previous reports an appropriation was made in 1913 for the purchase of several acres as an extension to the western boundary of the park, but legal proceedings and complications incident to adjustment of values and benefit assessments caused such delay that the appropriation, not being a continuing one, lapsed on June 30, 1915, and Congress has failed to renew the allotment for this much desired improvement.

Many important needs are urged by the superintendent, some of which I have mentioned year after year. One of these is an aviary building for the birds now being housed in temporary quarters greatly deleterious to their health. Other needs are a building for the elephants, hippopotami, and similar animals; an ape house; a reptile house; a pheasantry; an ostrich house; an aquarium; and an insectary; also a gatehouse and a permanent boundary fence.

THE ASTROPHYSICAL OBSERVATORY.

Observations of the solar constant were continued at Mount Wilson, Cal., from July to October, 1915, and were begun again in 1916.

During the year there was published the results of solar-constant observations made under Prof. Pickering's direction at Arequipa, Peru, since August, 1912, with a silver-disk pyrheliometer lent by the Smithsonian Institution. These observations confirm the variations of the sun observed at Mount Wilson. An interesting feature of the Arequipa observations was the fact that the volcanic eruption of Mount Katmai in 1912, which produced a great deal of dust over the northern hemisphere, apparently had no effect on the atmosphere south of the equator.

The results of observations at Mount Wilson in 1913 and 1914 on the distribution of radiation along the diameter of the sun's disk were published during the year. It is thus shown that the average distribution over the disk varies from year to year as well as from day to day.

Observations have been continued on the transmission of rays of great wave length through long columns of air, which it is expected will be of much interest in studying the earth's temperature as dependent on radiation toward space.

After several years of experimenting the Astrophysical Observatory has constructed an instrument called the pyranometer, designed for measuring the intensity of sky light by day and of radiation outward toward the sky by night. A full account of this instrument has been published in pamphlet form. The pyranometer may prove of advantage in botanical investigations in forests and greenhouses, since it can measure radiation in deep shade as well as in the full sun.

The Institution has made an allotment from the Hodgkins fund for carrying on solar-constant work at some suitable place in South America. Throughout the year, for several years, it is intended to continue observations at Mount Wilson in California and at the South American station with a view to determine the dependence of the earth's climatic conditions on the sun's variation of radiation. In addition to his solar-constant work the director of the observatory has given considerable attention to experiments at Mount Wilson with solar cooking apparatus "comprising ovens heated by oil under gravity circulation maintained by heat collected by a concave cylindric mirror of about 100 square feet surface." These experiments were not concluded at the close of the year.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

The International Catalogue of Scientific Literature, the United States bureau of which is administered by the Smithsonian Institution, was organized in 1901, and since that date 17 volumes of references to scientific literature, one for each of 17 branches of science, have been published each year. During the past year 24,160 classified references to American scientific literature were prepared by the United States bureau, bringing the total number of references to the literature of this country since the inception of the catalogue up to 369,509.

As stated in last year's report, the war in Europe caused considerable financial embarrassment to the publication of the catalogue owing to the impossibility of collecting subscriptions from several of the countries involved. The generosity of the Royal Society of London in making up this loss of income made possible the publication of the thirteenth annual issue, and this year a request was made for assistance from the United States. Your secretary succeeded in interesting the Carnegie Corporation, of New York, in the project and through the generous assistance of that establishment it was made possible to publish the fourteenth annual issue.

The value to science of this catalogue is universally recognized, and it is the opinion of scientists everywhere that any lapse in its publication would be a real calamity, as shown by the action of the Inter-

national Council of the Catalogue in voting to extend the work to at least 1920.

NECROLOGY.

James Burrill Angell, doctor of laws, died April 1, 1916. He had been a regent of the Institution for a quarter of a century, from January 19, 1887, to January 15, 1912, when he resigned on account of age and inability longer to attend meetings of the board. He was born at Scituate, R. I., January 7, 1829, and through his long life as a journalist, an educator, and a diplomat he served his country faithfully in many positions of honor and trust.

He began his career as a professor of modern languages at Brown University, was a journalist during the period of the Civil War, president of the University of Vermont 1866–1871, president of the University of Michigan 1871–1909, United States minister to China 1880–1882, and minister to Turkey 1897–98, and served on several important treaty commissions. In accepting his resignation as a regent in 1912 the board recorded its appreciation of his long and faithful service to the Smithsonian Institution.

Respectfully submitted.

Charles D. Walcott, *Secretary.*

APPENDIX 1.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

SIR: I have the honor to submit the following report on the operations of the United States National Museum for the fiscal year ending June 30, 1916:

INTRODUCTORY.

Seventy years ago Congress first definitely recognized the national collections and directed their segregation and preservation under the custody and supervision of the Smithsonian Institution in the building to be erected for that establishment. By 1850 arrangements had been sufficiently perfected to justify the appointment of an assistant in charge of museum matters and to begin the acquisition of natural-history specimens, but it was not until 1858 that the extensive collections which had previously accumulated at the Patent Office could be accepted. With an influx of material relatively as phenomenal as in more recent years, the Museum rapidly spread beyond the boundaries originally assigned to it and by 1875 was practically in possession of all parts of the Smithsonian building not required for the offices of the parent institution. But even so, there was a condition of great congestion from which relief was only obtained in 1881, the year of the completion of the second building. Though specially designed for displaying the many important donations in numerous branches of the industrial arts from the Centennial Exhibition of 1876, the latter had also to serve for the overflow in natural history, a combination which fully taxed its capacity in less than three years. Then followed nearly three decades during which about as much material was assembled in outside storage as found lodgement within the two structures.

The problem as regards the departments of natural history was solved when the new large granite building was made ready for occupancy in 1911, except that it lacked accommodations for the division of plants, or National Herbarium. As the depository for the Department of Agriculture and other establishments conducting extensive botanical explorations, this branch of the Museum has about outgrown its provisional quarters in the Smithsonian building, and its future requirements should not long go unheeded.

The most serious phase of the situation now confronting the Museum, however, results from the wholly inadequate facilities for systematically developing the collections illustrative of the industrial arts. Comprehended under the fundamental act, partly organized in 1880, greatly enriched from the Philadelphia exhibition of 1876, and with a steady growth through all subsequent years, this important department, whose principal aim is popular education on technical lines by means of exhibits visualizing conditions and processes as well as products, is filling to such an extent every foot of available space that the halls present rather the appearance of gross storage than of orderly and classified arrangement. Public sentiment, expressed through many channels, demands better progress than heretofore in carrying out the purposes of this department, but the difficulties in the way are by no means confined to limitations of space, since the more immediate embarrassments arise from an insufficiency of funds for employing the necessary skilled assistants required for working up and preparing the exhibits, which includes the construction of many models.

The department of the fine arts is even more poorly provided for than any of the other Museum branches, as it is occupying borrowed space which is already so crowded as seemingly to forbid further contributions, and while this condition lasts there can be little hope for advancement. There is, however, one bright feature to mention in this connection—the decision to immediately begin the erection of the building for the Charles L. Freer collections of American and oriental art, the plans showing a beautiful granite structure, the completion of which will bring to the Institution much the largest donation it has ever had, one of the most notable gifts of its character in the world's history. Put to no expense for either building or collections, it is hoped that the example set by Mr. Freer will lead to more liberal consideration on the part of the Government of the needs of the National Gallery of Art, for which no appropriations of any kind have ever yet been made.

During the past year many valuable additions were made to the collections generally, new and instructive features were incorporated in the exhibition halls, and a wider public interest was stimulated through an exceptional number of meetings and of special expositions of scientific and art objects held at frequent intervals in the convenient quarters provided for such purposes.

COLLECTIONS.

The total number of specimens acquired during the year was approximately 243,733. Received in 1,525 separate accessions, they were classified and assigned as follows: Department of anthropology, 29,493; zoology, 120,303; botany, 40,631; geology and mineralogy,

1,700; paleontology, 48,403; textiles, woods, and other animal and vegetable products, 2,304; mineral technology, 280; and the National Gallery of Art, 619. As loans for exhibition, 1,960 articles were also obtained, mainly for the Gallery of Art and the divisions of history and ethnology. Material for examination and report, consisting chiefly of rocks, ores, fossils, and recent animals and plants, was received to the extent of 1,036 lots.

Anthropology.—One of the most desirable ethnological additions was a series of costumes, weapons, and utensils—excellent illustrations of the arts and industries of recently discovered tribes in the interior of British Guiana, collected by Mr. John Ogilvie. The aborigines of Celebes and Borneo were represented by many important objects assembled by Mr. H. C. Raven and presented by Dr. W. L. Abbott; and those of the Philippine Islands by extensive and varied contributions, including weapons, musical instruments, baskets, costumes, etc., received from Mrs. Caroline E. Bates, Mr. E. H. Hammond, and the following officers of the United States Army, namely, Maj. Edgar Russel, Maj. W. T. Johnston, and Capt. J. R. Harris. Baskets, ornaments, and other articles of various Indian tribes of North America, were also given by Mrs. Bates; a number of rare and valuable objects from the Osage Indians were deposited by the Bureau of American Ethnology; interesting examples of art and ethnologica from various parts of the world were presented by Miss Louise Salter Codwise; and costumes and implements from the Blackfeet Indians and the Greenland Eskimo were likewise obtained.

An extensive collection of archeological material from mounds and ruin sites in Utah, resulting from explorations by Mr. Neil M. Judd for the Bureau of Ethnology, is of particular value in aiding to determine the distribution of Pueblo culture toward the north. Other accessions from America consisted mainly of artifacts, including many rare specimens, from several of the States, and of woven fabrics and pottery from Peru. A gift of Old World antiquities from Miss Codwise was composed principally of Egyptian scarabs, necklaces, and figurines, and Palestinian amulets, while a collection of prehistoric stone implements from Great Britain contained some choice specimens.

The division of physical anthropology received many skeletons and skulls, in very complete condition, from Mr. Clarence B. Moore, who obtained them at "The Indian Knoll," on the Green River, Ky.; and a similar collection from Mr. George G. Heye, secured during an exploration of old burial sites in Georgia and Tennessee. Especially noteworthy was an excellent series of skulls and numerous other bones belonging to the period before the advent of the whites, procured in old burial caves in Hawaii by Mr. August Busck.

The more notable accessions in mechanical technology bore upon the subjects of the telephone and firearms. The American Telephone & Telegraph Co. contributed a set of instruments and of loading coils, with examples of line wire and glass insulators, used at the opening of the first telephone line between New York and San Francisco on January 25, 1915, and also a duplicate of the first instrument through which speech was transmitted electrically in Boston in 1875; while Dr. Alexander Graham Bell deposited his diplomas, certificates of award, and announcements of election to scientific societies, an interesting series of documents indicative of the many honors which have been conferred upon him. A gift from Mrs. Bates of much historical value included old military guns of European and American manufacture, pistols and revolvers, a gun made in the Philippine Islands, two very fine bronze swivel cannon, and several Toledo blades and other swords.

Mr. Hugo Worch added three old American pianos to his munificent donation of the previous year, and made a provisional deposit of four other instruments, three American and one of London make. The permanent acquisitions in ceramics consisted mainly of examples from some of the prominent potteries of the United States, but among the loans were specimens of porcelains from abroad and also of glassware, bronze, and brass, which are now exhibited in the ceramic gallery.

Among the accessions in graphic arts were experimental apparatus and pictures illustrating progress and the several steps in the electrical transmission of photographs from one place to another, as also the development of the engraving machine called the akrograph; a Wells printing press; examples of the art of overlay in printing; samples of poster stamps and lithographs; and a number of fourteenth and fifteenth century manuscripts. The additions in photography included daguerreotypes, ambrotypes, and tintypes; a sepia print of a painting on carved wood by Rosselimo; and a series of prints of astronomical subjects from the Yerkes Observatory.

American history.—The historical collections were increased to an exceptional extent by both gifts and deposits. Most prominent was a loan by Mr. Walter G. Peter, a descendant of Martha Washington, of many objects of artistic and domestic interest once the property of General and Mrs. Washington at Mount Vernon, which richly supplement the Lewis collection long in the possession of the Museum. Mention can here be made of only a few of the articles, among which were a china portrait plaque of Washington designed by Richard Champion; a water-color portrait of him by William Thornton; two gold lockets containing locks of his hair; a gold watch of Mrs. Washington, the cover engraved with the Washington coat of arms; a child's French dressing table of exquisite workman-

ship presented by Lafayette to the granddaughter of Mrs. Washington, Martha Custis, who became Mrs. Thomas Peter; letters written to Mrs. Washington on the death of her husband; documents relating to the settlement of her estate; and a number of fine examples of eighteenth century china and glassware.

It is pleasing to note that the valuable loan collection of memorials of Gen. William Tecumseh Sherman, United States Army, with some additions, was given into the permanent keeping of the Museum during the year by his son, Hon. P. Tecumseh Sherman. From the widow and children of Maj. Gen. Henry W. Lawton, United States Volunteers, there was acquired as a gift an extensive series of objects, including a medal of honor from Congress, forming a significant reminder of the distinguished career of this officer in the Civil War, several Indian wars, and the Philippines. Important relics of Capt. Edward Trenchard, United States Navy (1784–1824), and of his son, Rear Admiral Stephen Decatur Trenchard, United States Navy, including two presents awarded to the former by acts of Congress, were received on deposit. There were also many other gifts and loans of notable personal and period relics, and the national societies of the Colonial Dames of America and the Daughters of the American Revolution made interesting additions to their already extensive loan collections.

By the death of Mr. David W. Cromwell, of New York, on September 11, 1915, the splendid collection of nearly 20,000 domestic and foreign postage stamps, which he placed on permanent deposit in 1908, became the absolute property of the Museum. Among other additions in philately, including stamps, stamped envelopes, and post cards, were 1,565 new foreign and 269 new domestic issues, received from the Post Office Department.

The collection of historical costumes was enriched to the extent of 562 articles, nearly all of which were loans. To the series of costumed figures representing hostesses of the White House four were added, namely, Mrs. James Monroe, Mrs. John Quincy Adams, Mrs. Abraham Lincoln, and Mrs. James R. McKee.

Biology.—In the accessions of vertebrate animals the Asiatic region was especially well represented, and many genera and species new to the collection were obtained. The name of Dr. W. L. Abbott remains conspicuous in this connection through three contributions. The first, composed of material gathered under his direction and at his expense in Celebes and Borneo by Mr. H. C. Raven, consisted of 465 mammals, 869 birds, and a number of reptiles and batrachians. The second, presented jointly with Mr. C. B. Kloss, contained 197 mammals and 133 birds, besides reptiles and batrachians from Siam; while the third was a series of 183 mammals from Kashmir, British India. The Celebes and Siam specimens are especially important,

both as coming from localities not hitherto represented in the Museum and as supplementing the existing large collections from the related faunal regions of the Malay Peninsula, the Philippine Islands, and Borneo. From northern China and Manchuria was received a valuable series of mammals, birds, and reptiles, the results of further field work by Mr. Arthur de C. Sowerby. Obtained by Mr. Copley Amory, jr., during a collecting trip to the little-known Kolyma River region of northeastern Siberia and presented by him, were 365 mammals and 243 birds, besides a number of nests and eggs of the latter.

Additional mammals were received from Baluchistan through exchange with the McMahon Museum at Quetta and from East Africa as a gift from Mr. Elton Clark. The most important accessions of reptiles, batrachians, and fishes consisted of the specimens obtained in connection with the Smithsonian biological survey of the Canal Zone by Mr. S. F. Hildebrand, Prof. S. E. Meek, and Mr. E. A. Goldman, the number of fishes amounting to about 18,000. An extensive collection of Peruvian fishes made by Dr. R. E. Coker in 1907 and 1908 was presented by the Government of Peru, and another from South American localities was received from Indiana University in exchange. The Bureau of Fisheries deposited 1,242 specimens from *Albatross* explorations in the Pacific Ocean.

The receipts by the division of marine invertebrates were exceptionally extensive. Twenty-seven separate collections were transferred by the Bureau of Fisheries, a part of which had been worked up and described. They represented investigations by the steamer *Albatross* in the Pacific Ocean, by the steamers *Fish Hawk* and *Bache* and the schooner *Grampus* in the Atlantic Ocean and contiguous waters, and certain other inquiries. Of crustaceans there were about 15,000 specimens, of annelids about 1,000 specimens, of pteropod mollusks about 3,200 specimens, of starfishes nearly 150 types, and of fresh-water mollusks about 1,000 specimens from the Mississippi River, besides very many unassorted lots of crustaceans, salpa, pyrosoma, and other groups.

A very large number of miscellaneous invertebrates from the Danish West Indies and about 5,000 specimens of land and marine mollusks from the Florida Keys were deposited by the Carnegie Institution of Washington, while over 3,000 miscellaneous specimens from dredgings off the coast of Florida and about 7,000 land and fresh-water shells from Cuba were presented by Mr. John B. Henderson. An accumulation of samples of ocean bottom, filling nearly 11,000 bottles, obtained by vessels of the Coast and Geodetic Survey during hydrographic investigations in the Atlantic and Pacific Oceans and the Gulf of Mexico, were transferred to the custody of the Museum.

The principal accessions of insects consisted of Lepidoptera and Diptera deposited by the Bureau of Entomology, of named species of beetles and Hymenoptera from Australia, and of types of new species presented by Prof. T. D. A. Cockerell.

The division of plants received several large and important collections. The Department of Agriculture transferred over 6,600 specimens, of which a considerable proportion were grasses. Some 8,000 specimens, representing the field work of Dr. J. N. Rose in connection with his cactus investigations in Brazil and Argentina during the summer of 1915, were deposited by the Carnegie Institution of Washington; and about 2,000 specimens secured by the Peruvian expedition of 1914–15 were presented by the National Geographic Society and Yale University. Among other important accessions were specimens from the Philippines, Amboina, China, and Panama.

Geology.—During explorations in the Rocky Mountain region in the summer of 1915, Dr. Charles D. Walcott procured for the Museum in the Yellowstone National Park a large and well-selected series of the siliceous and calcareous sinters, including some masses of exceptional size, native sulphur, silicified wood, sundry mineral specimens, and an extensive representation of volcanic rocks, intended in part for an exhibition of the geological features of that park. Among other important acquisitions were illustrations of the geology and mineral associations of the pegmatite deposits of southern California, and of the emerald mines at Muzo, Colombia; a number of scheelite specimens of more than ordinary interest from Utah; and an unusually fine large specimen of secondary copper sulphate from the Silver Bow Mine, Mont. The Geological Survey transferred examples of the nitrate deposits in Idaho and Oregon, and of potash-bearing salts and associated rocks from the vicinity of Tonopah, Nev.; and Dr. Joseph P. Iddings presented some fine specimens of the peculiar problematic bodies known as obsidianites and Darwin glass from Borneo and Tasmania, and an important series of phosphate rocks from Ocean and Makatea Islands.

By the will of Dr. Charles Upham Shepard, who died early in July, 1915, the very important collection of meteorites belonging to him, which has been on deposit for a number of years, was bequeathed to the Museum; while from several other sources material representing 32 distinct falls of meteorites in many different parts of the world was also acquired.

The mineral collection received many additions, including exceptionally fine specimens, examples of recent finds and several rare species, the largest accession, a deposit from the Geological Survey, consisting of about 300 specimens mostly illustrative of a report by Dr. W. T. Schaller on the gem minerals of the pegmatites of California. From the same Survey was also transferred a large amount

of petrological material, mainly rocks illustrating the geology and ore deposits of several districts and localities, described in recent papers.

Of fossil invertebrates the Geological Survey made extensive contributions from the Tertiary of the Atlantic and Gulf coastal plain, the Cretaceous of New Mexico, and other formations and localities. Other important accessions were several thousand specimens of bryozoa and ostracoda from various parts of the world, a collection of Upper Cretaceous forms of special interest as containing types described long ago by Prof. T. A. Conrad, insects from the Florissant beds of Colorado, and types of new species of crabs.

Most prominent of the additions in vertebrate paleontology was a nearly complete skeleton of a large mastodon found near Winamac, Ind., which has already been mounted and placed in the exhibition hall. From the Koren expedition to the Kolyma River region of northeastern Siberia were received nearly 200 specimens, of which the most valuable is a fine skull of the Siberian mammoth, the only one of this northern form now in any American museum. Two collections of fossil plants, recently described, including the type and figured specimens, were transferred by the Geological Survey. One was from the San Juan Basin, N. Mex., the other from the Fox Hills formation, Colo.

Textiles.—In the division of textiles excellent progress was made in the acquisition and installation of new exhibits. Probably the most important was an extensive series of specimens, and of models, sections, and photographs of machinery from the American Thread Co., showing the manufacture of cotton thread in all its details. Other noteworthy accessions were two additional Jacquard machines for decorating textiles; further illustrations of the operation and work of the embroidery automats, of the manufacture of silk fabrics, and of the designing, weaving, and printing of silk upholstery and drapery materials; examples of Javanese batik work on cotton and silk, and of various patterns of moiré silks; a demonstration of the successive stages in the production of painted cut velvet, called "Yuzen Birodo" by the Japanese; and samples of silk skein-dyeing and silk piece-dyeing and printing.

The Japanese Commission to the Panama-Pacific International Exposition contributed 100 commercial fabrics, including many kinds not produced in this country. The representation of American upholstery and drapery fabrics and allied textiles of various materials and character of decoration was greatly increased and improved, and manufacturers continued to keep the collection supplied with novelties and new types and designs of dress fabrics as soon as they were brought out. Numerous excellent examples of the handicraft work done in the schools of the Philippine Islands were also obtained.

Wood technology.—In the recently organized section of wood technology there were many accessions of samples of important commercial woods and of illustrations of wood utilization, the public installation of which was about to be taken up at the close of the year. While the wood specimens, mostly in the form of large boards, were intended primarily for practical educational purposes, a large proportion had been determined botanically, insuring for them a proper technical designation.

The principal collection of wood samples, from the Philippine Islands, consisted of 110 pieces, representing 85 species, the duplicates showing different characteristics as to grain and figure. In addition there were 16 pieces and 15 species from Argentina; 32 specimens of various foreign woods highly prized for veneers and for cabinet and furniture work, including the several important varieties which are imported into this country under the trade name of mahogany; 38 specimens of redwood from the Pacific coast, representing a large range of patterns produced by the manufacturers and some of their better grades of plain lumber; and also examples of koa and ohia woods from Hawaii, Honduran mahogany, red gum, yellow poplar, white oak, and black cherry.

Material received as part of an exhibit of the turpentine industry included three butt sections of longleaf pine from a commercial turpentine orchard, illustrating the manner in which gum for the distillation of turpentine is obtained by the box, the cup and gutter, and the Forest Service methods, clearly showing the progressive improvement from the former wasteful to the modern economical processes. These were accompanied by samples of the gum, scrape, turpentine, and resin, and examples of the tools used, and, in addition, there was a model of a turpentine still of a pattern common to the longleaf pine belt, in a setting typical of the region, some of the trees being boxed and others provided with cups and gutters. The utilization of wood was also illustrated by samples of dyewoods in the log, and a series of extracts from them, including logwood, Brazil wood, fustic, and quebracho; and by several series of specimens showing the materials and successive stages in the manufacture of a number of articles of common use, such as matches, tool handles, brushes, and sporting goods.

Of subjects other than textiles and woods, while no special efforts were made in their behalf, much desirable material was received, including agricultural products generally, foods, medicines, resins, models of fishing methods and boats, fishery products, etc.

Mineral technology.—A very realistic model of Trinidad Asphalt Lake and its environs, a series of colored transparencies and photographic enlargements, and a complement of specimens typifying the

different forms of asphalt occurrence as well as the useful products prepared therefrom, constituted the most striking addition to the exhibits in the division of mineral technology. Next may be mentioned a complete ore stope removed bodily, ore faces, timbering, chute, manway, and all accessories, from the Copper Queen Mine at Bisbee, Ariz.

Among other important acquisitions were a model representing the layout of a Portland cement plant and the sequence of operations connected with the manufacture of cement; an industrial series of specimens covering the occurrence and uses of natural graphite, including a remarkable block of pure graphite weighing 250 pounds; a model reproducing the unique method of mining placer gravel for gold in the frozen north by a system of underground drifting or tunneling bedrock, with the ground thawed out in immediate advance of the tunnel by means of steam; and a model of a cyanide leaching plant showing admirably the method commonly employed in the extraction of gold from its ores where the metal does not lend itself to simpler and more direct processes for its segregation.

NATIONAL GALLERY OF ART.

It is very gratifying to note that early in the year Mr. Charles L. Freer waived the condition attending his munificent gift of American and oriental art to the effect that the collection remain in his possession during his life, and expressed a desire that the erection of the building be taken up at the earliest possible moment. The sum required for this purpose, $1,000,000, also a donation from Mr. Freer, was turned over to the Institution in December, and the site and preliminary plans, both satisfactory to the benefactor, received later the approval of the Board of Regents of the Institution, and of the Federal Commission of Fine Arts. The site is the southwestern part of the Smithsonian reservation, at the corner of Twelfth and B Streets, S. W., and approximately two years will be required for the completion of the building, at the end of which time the transfer of the many precious objects to Washington may be expected to take place. The fact that the planning and the execution of the work of construction is in the hands of Mr. Charles A. Platt, of New York, insures their being carried out in an eminently satisfactory manner.

Since the last report Mr. Freer has increased the extent of his collection to about 5,346 items by 535 additions, of which 23 are paintings and sculptures by the American artists Tryon, Thayer, Metcalf, Murphy, and Saint-Gaudens; while the oriental objects, numbering 512, consist mainly of paintings, pottery, bronzes, and jades from China, Korea, and Japan. Mr. Freer announces considerable headway in the preparation of the final catalogues, on which a number of experts of wide repute are at work.

The National Gallery of Art also received during the year from the Department of State a most interesting collection of 82 drawings in pencil, pen, charcoal, chalk, crayon, and water color, executed by eminent contemporary French artists and presented to the people of the United States by the citizens of the French Republic as a token of their appreciation of the sympathetic efforts of American citizens toward relieving the distress occasioned by the European war. There should likewise be mentioned an oil portrait of Abraham Lincoln, by George H. Story, presented by Mrs. E. H. Harriman.

MEETINGS AND CONGRESSES.

The auditorium and committee rooms in the new building were utilized to a much greater extent than in any previous year for scientific and art meetings, lectures, and other functions. Three of the local societies made the Museum their regular meeting place, among these being the Washington Society of the Fine Arts, which presented its customary three courses of lectures. Annual or special meetings were held by the National Academy of Sciences, the Mining and Metallurgical Society of America, the Society of American Foresters, the American Oriental Society, and the American Surgical Association. Lectures, singly or in short series, were given under the auspices of 10 of the science and art societies, and 6 receptions were held in connection with large gatherings of national and international bodies.

Among the special meetings there were several which merit distinctive mention. The most important of these was the Nineteenth International Congress of Americanists which met from December 27 to 31, in affiliation with Section I of the Second Pan American Scientific Congress, then also in session in Washington, the American Anthropological Association, the American Folk-Lore Society, the American Historical Association, and the Archaeological Institute of America. On the afternoon of February 9 a bronze tablet in memory of Prof. S. F. Baird as the instigator of the Federal fishery service, a contribution to the Bureau of Fisheries by 47 subscribers, was dedicated in the auditorium with appropriate ceremonies in the presence of a large assemblage.

During the week of the safety-first exhibition, February 21–28, the auditorium was occupied on five days for lectures and discourses on the subjects comprehended by this notable display, nearly all of them being profusely illustrated, both motion pictures and lantern slides being used. The speakers, besides the Secretary of Labor and several assistant secretaries of departments, were all experts in the several bureaus represented. The exercises attending the centenary celebration of the organization of the Coast and Geodetic Survey,

held in the auditorium on April 5 and 6, consisted of an exposition of the work of this, the first scientific service of the Government, by eminent authorities who had been invited to speak upon those phases of the Survey's activities with which they are best acquainted.

The American Association of Museums held its eleventh annual meeting in Washington from May 15 to 18, and the American Federation of Arts its seventh annual convention from the 17th to the 19th of the same month. While only one session of the former and none of the latter was held in the Museum, a reception was tendered to both on the evening of May 17, when an important loan exhibition of the industrial arts was opened with a special view.

SPECIAL EXHIBITIONS.

The educational efforts of the Museum were most notably served by several large and important special exhibitions. Supplementing the arrangements for the meetings of the Congress of Americanists and affiliated societies during convocation week, an interesting installation was made of material relating to pertinent subjects.

During the week of February 21–27 the foyer, with three of its communicating rooms, was occupied by one of the most remarkable and interesting Government exhibitions that has ever been assembled. Having as its theme the "safety-first" idea, it was participated in by 20 bureaus, the American National Red Cross Society, and the Metropolitan police department, the activities of all of which are primarily for or comprehend in a marked degree the safeguarding of life and property, as well as the prevention and care of disease. Although the available area was restricted the display proved most effective and satisfactory, as it was also comprehensive, probably nothing in the Government service relating to "safety first" having escaped some representation. Attention was widely called to the exhibition in advance. The governors of States were notified of the nation-wide aspect of the exposition, one of the results of which was to bring about a meeting of State mine inspectors in the Museum, and manufacturers and operators from all over the country were invited to be present. The total attendance of visitors during the week was 35,447.

The exercises commemorating the centenary of the Coast and Geodetic Survey, held on April 5 and 6, were supplemented by an exhibition in the foyer, the purpose of which was to illustrate the appliances and methods used and the results obtained in both its marine and geodetic work during the 100 years of its existence. The material was admirably selected and arranged, constituting one of the most complete and instructive special displays ever installed in the Museum.

The models and drawings submitted in competition for the monument at Fort McHenry, Baltimore, in memory of Francis Scott Key, author of the "Star-Spangled Banner," and the soldiers and sailors who participated in the battle of North Point and the attack on Fort McHenry in the War of 1812, were arranged in the rotunda of the new building, where, after having been passed upon by the jury of awards, they were exhibited to the public from May 17 to June 17.

The exhibition of American industrial art, held during the spring and summer of 1915 under the auspices of the American Federation of Arts, was repeated as a feature of the seventh convention of this association, being opened on May 17, 1916, and continuing for one month. The foyer and five of its communicating rooms were occupied. The exposition was designed to bring together examples of art on industrial lines, both hand and machine made, to show what is being produced in this country, and though not exhaustive in any particular, some of the best-known art workers of the country participated, and it was felt that a fairly high standard had been maintained.

Following the close of the Panama-Pacific International Exposition on December 4, and in accordance with an act of Congress, a large part of the Museum's ethnological exhibit was transferred from San Francisco to the Panama-California International Exposition at San Diego, to be shown there until the end of the calendar year 1916. The selection made for this purpose consisted of four large family groups of Eskimo, Zulu-Kaffirs, Caribs, and Dyaks; miniature dwelling groups of aboriginal peoples in many parts of the world; four cases of artifacts; and a set of lithographs from Catlin's North American Indian paintings.

MISCELLANEOUS.

Duplicate material to the extent of over 7,000 specimens, classified and labeled for teaching purposes and arranged in 96 sets, was distributed to schools and colleges, the subjects principally represented being rocks, minerals, ores, fossils, and recent mollusks. For obtaining additions to the collections through the medium of exchange, about 9,400 duplicates, chiefly from the natural-history divisions, were utilized. A large number of specimens were sent for study to collaborators of the Museum and other specialists. They consisted mainly of plants, recent animals, and fossils, and were contained in 114 lots.

The attendance of visitors at the new building aggregated 316,707 for week days and 64,521 for Sundays, being a daily average of 1,012 for the former and of 1,240 for the latter. For the older Museum building, which is only open on week days, the total was 146,956 and

the daily average 469. The halls in the Smithsonian building, which were closed for renovation during about five months, received 48,517 visitors.

The publications of the year comprised 2 volumes of Proceedings and 4 Bulletins, besides the annual report and 52 separate papers belonging to the series of Proceedings and Contributions from the National Herbarium. The total distribution of Museum publications aggregated 73,798 copies.

Through the addition of 1,895 volumes, 72 parts of volumes, and 2,873 pamphlets, the number of volumes in the Museum library was increased to 47,713, and of pamphlets and unbound papers to 79,241.

Respectfully submitted,

RICHARD RATHBUN,
Assistant Secretary in Charge,
United States National Museum.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

OCTOBER 30, 1916.

Appendix 2.

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY.

Sir: I have the honor to submit the following report on the operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1916, conducted in accordance with the provision of the act of Congress approved March 3, 1915, making appropriations for the sundry civil expenses of the Government, and with a plan of operations submitted by the ethnologist in charge and approved by the Secretary of the Smithsonian Institution. The provision of the act authorizing the researches of the bureau is as follows:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, including the excavation and preservation of archeologic remains, under the direction of the Smithsonian Institution, including necessary employees and the purchase of necessary books and periodicals, $42,000.

Mr. F. W. Hodge, ethnologist in charge, devoted most of his energies, as usual, to administrative affairs. However, in pursuance of a plan for cooperative archeological research by the Bureau of American Ethnology and the Museum of the American Indian (Heye Foundation) of New York, Mr. Hodge early in July joined Mr. George G. Heye, of the museum mentioned, in the excavation of the Nacoochee mound in White County, northeastern Georgia, permission to investigate which was accorded by the owner, Dr. L. G. Hardman.

The Nacoochee mound is an earthwork occupied by the Cherokee Indians until early in the nineteenth century. The name "Nacoochee," however, is not of Cherokee origin; at least, it is not identifiable by the Cherokee as belonging to their language, and by no means does the word signify "the evening star" in any Indian tongue, as one writer has claimed.

The summit of the mound, which had been leveled for cultivation about 30 years ago, measured 83 feet in maximum and about 67 feet in minimum diameter; the height of the mound above the adjacent field was 17 feet 3 inches, and the circumference of the base 410 feet. These measurements are doubtless less than they were at the time the mound was abandoned by the Cherokee, as all the dimensions

have been more or less reduced by cultivation, the slope at the base particularly having been plowed away for several feet. The mound was reared both for domicile and for cemetery purposes and was composed of rich alluvial soil from the surrounding field. Excavation determined that the mound was not built at one time, but evidently at different periods, as circumstances demanded. This was shown plainly by the stratification of the mound soil, the occurrence of graves at different depths with undisturbed earth above them, the presence of fire pits or of evidences of fires throughout the mound at varying levels, and by the finding of a few objects derived from the white man in the upper part and in the slopes of the mound, but not in the lower levels. From this last observation it is evident that the occupancy of the mound extended well into the historical period, a fact supported by the memory of the grandparents of present residents of the Nacoochee Valley, who recalled the mound when the Cherokee Indians still occupied it and the surrounding area.

The fact that the mound was used for burial purposes is attested by the finding of the remains of 75 individuals during the course of the excavations, the graves occurring from slightly beneath the summit to a depth of about 19 feet, or below the original base of the mound. These graves, with few exceptions, were unmarked, and in most instances were not accompanied with objects of ceremony or utility. The exceptions were those remains with which were buried stone implements, shells or shell ornaments, a smoking pipe, a pottery vessel, or the like. The skeletons were found usually with the head pointed in an eastwardly direction, and were all so greatly decomposed that it was impossible to preserve any of them for measurement and study, the bones in most cases consisting of only a pasty mass.

As mentioned above, most of the burials were unmarked. The exceptions consisted of two graves incased and covered with slabs of stone, both unearthed near the very base of the mound. One of these stone graves contained a skeleton the bones of which were largely of the consistency of corn meal, owing to the ravages of insects, but what was lacking in the remains themselves was more than compensated by the finding near the skull of a beautiful effigy vase of painted pottery, the only piece of painted ware, whole or fragmentary, found in the entire mound. The occurrence of this type of vessel and the presence of the stone graves at the bottom of the mound suggest the possible original occupancy of the site by Indians other than the Cherokee.

Perhaps the most remarkable feature of the mound was the large number of smoking pipes of pottery, mostly broken, but in many forms and of varying degrees of workmanship. Some of the pipes are of excellent texture and are highly ornamented with conven-

tionalized figures of birds, etc., or marked with incised designs. Another feature of the mound was the presence of a great amount of broken pottery, especially in the refuse at the base and covering the slopes. This pottery is chiefly of fine texture, although some of the cooking vessels are of coarse ware. With the exception of the painted vessel above noted, the only ornamentation applied by the makers of the pottery consists of incised and impressed designs, the latter made usually with a paddle of clay or wood, or worked out in the moist ware before firing by means of a pointed tool, a spatula, a piece of cane, or a shell.

In pursuance of another plan of cooperative archeological research, Mr. Hodge, in October, visited Zuñi, N. Mex., with Mr. Heye, for the purpose of examining the ruins of the historic pueblo of Hawikuh, in the Zuñi Valley southwest of Zuñi pueblo, and of making the necessary arrangements with the Indians for its excavation. This site is of great archeological and historical interest, as the pueblo was inhabited when first seen by Fray Marcos de Niza in 1539, and when visited and stormed by Coronado in the following year. It became the site of an important Franciscan mission in 1629, and was finally abandoned in 1670 on account of depredations by hostile Indians. By reason of the fact that Hawikuh was inhabited continuously from prehistoric times until 130 years after the opening of the historical period, it is expected that a thorough study of its ruins will shed important information on the effect of the earliest Spanish contact with the Zuñi people and will supplement archeological work conducted in other village sites of that tribe. Owing to unforeseen circumstances, active work was not commenced before the close of the fiscal year, but it is hoped that its initiation will not be long delayed. A permit therefor has been granted by the Secretary of the Interior.

By provisional agreement with the School of American Archæology at Santa Fe, N. Mex., and the Royal Ontario Museum of Archæology at Toronto, plans were perfected whereby the Smithsonian Institution, in conjunction with those establishments, was to conduct archeological researches of an intensive character in the Chaco Canyon of northern New Mexico, one of the most important culture areas north of Mexico. Although every effort was made to obtain from Congress the necessary appropriation for meeting the Institution's share of the expense (a permit for the excavations having been issued by the Secretary of the Interior), the project was presented too late for action, hence the work, so far as the Smithsonian Institution is concerned, has been necessarily postponed.

As opportunity offered, the preparation of the bibliography of the Pueblo Indians was continued by Mr. Hodge, who also represented the Smithsonian Institution as a member of the United States Geographic Board, and the Bureau of American Ethnology at the meet-

ings of the Smithsonian advisory committee on printing and publication.

Dr. J. Walter Fewkes, ethnologist, having been detailed to continue the excavation and repair of prehistoric ruins in the Mesa Verde National Park, Colo., under the joint auspices of this Bureau and the Department of the Interior, left Washington for that locality in August, 1915, and remained in the park continuously until the close of October. Dr. Fewkes devoted his attention mainly to a large mound of stones and earth situated near the point of a promontory opposite Cliff Palace, across Cliff Canyon, the excavation of which revealed a type of structure hitherto unknown in the Mesa Verde National Park, and architecturally different from any that had been previously excavated in the Southwest. The rooms of this building, which Dr. Fewkes designates as "Sun Temple," were thoroughly cleared out, the débris removed, and the walls were repaired in such manner that they will not be likely to deteriorate for many years. A report on the work of excavation and on the structural features of this interesting building forms the subject of an illustrated pamphlet published by the Department of the Interior in June, 1916, under the title "Excavation and repair of Sun Temple, Mesa Verde National Park."

Structurally the Sun Temple consists of two parts—an original building, to which an annex is so united as to give the two a D-shape ground plan, the southern or straight wall of which extends almost exactly east-west. This wall measures 131 feet 7 inches in length; the highest wall of the structure is 11 feet 7 inches, the lowest 5 feet. The walls are massive, varying in thickness from 2 to 5 feet, and are composed of a core of rubble faced on both sides, the exposed stones having been carefully fashioned by hand and accurately fitted, although, as in the case of pueblo masonry generally, the stones are usually neither "broken" at the joints nor bonded at the corners. Nevertheless the walls of the Sun Temple display excellent structural qualities that will compare favorably with any of its class north of Mexico. Architectually the annex resembles certain tower-like structures in the ancient pueblo region, and in plan the whole ruin bears resemblance also to Pueblo Bonito in Chaco Canyon, N. Mex.

The building contains three circular rooms resembling kivas, or ceremonial chambers, still used by some of the Pueblo Indians, and many other rooms of unusual shape and doubtful significance. There was no indication that the Sun Temple had been roofed; indeed, there is strong evidence that the construction of the buildings was never finished. Dr. Fewkes was not able to determine the age of the Sun Temple, but he is of the opinion that it was built later

than Cliff Palace. One evidence of its antiquity, however, was observed, namely, a cedar tree growing from the top of the highest walls was found to have 360 annual rings of growth, indicating that it sprouted a few years after Coronado led his expedition into the Southwest in 1540.

The builders of the Sun Temple are supposed by Dr. Fewkes to have been the former cliff dwellers of the neighboring canyons. As to its purpose, he is of the opinion that the building was used primarily for worship, but that like other temples among primitive peoples it was intended secondarily as a place of refuge in case of attack, and for the storage of provisions. The impression of a fossil palm leaf on the corner stone at the southwestern angle is believed to mark a shrine where rites to the sky or sun god were performed long before the temple was built. It is this supposed shrine that suggested the name for the edifice.

On the completion of the excavation and repair of the Sun Temple, Dr. Fewkes similarly treated Oak-tree House, a cliff dwelling in the precipice of Fewkes Canyon above which stands the Sun Temple. A collection of artifacts found in this dwelling was gathered in the course of the excavation and later deposited in the National Museum.

En route to Washington, Dr. Fewkes visited the so-called "Buried City of the Panhandle," on Wolf Creek in Ochiltree County, Tex., which had been reported to the bureau by residents of the neighborhood and had become locally celebrated. The remains examined hardly justify the name given to the site, which in former days was used as an encampment by wandering Indians rather than by sedentary people. Dr. Fewkes's attention was drawn also to a supposed artificial wall which gave name to Rockwall, not far from Dallas, Tex., but on examination this was found to be a natural sandstone formation.

Dr. Fewkes returned to Washington in November and immediately prepared a report on his summer's work in the Mesa Verde National Park for the use of the Department of the Interior, an advance summary of which, issued by the department, was widely published in the newspapers. An account of the excavation and repair of Oak-tree House and Painted House, the largest cliff ruins in Fewkes Canyon, was also prepared for publication. On the completion of these tasks Dr. Fewkes devoted the remainder of his limited time to the preparation of the extended memoir on The Aborigines of the West Indies for publication in a report of the bureau. In June he again departed for the field with the view of initiating, before the close of the fiscal year, an inquiry into the archæological evidences bearing on Hopi legends that ancestors of the clans of the ancient pueblo of Sikyatki lived at Tebungki, or Beshbito, an oval ruin 15 miles east of Keams Canyon, Ariz. Dr. Fewkes visited and

surveyed the ruin and made photographs and notes thereof. He likewise investigated certain large ruins east of Tebungki, on the ancient trail of migration from Chaco Canyon, and traced for some distance the prehistoric trail running from San Juan Valley southward past the great ruins, as yet undescribed, near Crownpoint, N. Mex.

During the months of July to December, 1915, Mr. James Mooney, ethnologist, continued to devote most of his attention to the preparation for publication of the Cherokee Sacred Formulas, including transliteration, translation, and explanation of each formula, with complete glossary and botanic index. These formulas, collected by Mr. Mooney on the East Cherokee Reservation in North Carolina, are written in the Cherokee language and alphabet and held for their own secret use by priests of the tribe, most of them long since dead. They consist of prayers, songs, and prescriptions, dealing with medicine, love, hunting, fishing, agriculture, war, the ball play, self-protection, etc. They number in all between 500 and 550, contained in several manuscripts, as follows:

1. *Gadigwanasti* ("Belt," died 1888).—186 in a large blank book of foolscap size, and 94 others on separate sheets of the same size, closely written; 280 in all. Obtained from his son.

2. *A'yunini* ("Swimmer," died 1899).—Written in an unpaged blank book of 242 pages, 3½ by 12 inches, only partially filled; 137 in all. Obtained from himself and transliterated and translated with full explanation from his distation in 1888.

3. *A'wanita* ("Young Deer," died about 1892).—24 written on separate sheets and obtained from him in 1888. Transcribed later into No 4.

4. *Tsiskwa* ("Bird," died 1889).—22, dictated from deathbed and with other formulas written out in regular fashion, with index, in a blank book of 200 pages, 8 by 10 inches, by his nephew, W. W. Long (Willwesti), in 1889.

5. *Dagwatihi* ("Catawba Killer," died about 1890.—Written out from his dictation by W. W. Long, in No. 4, in 1889; 11 in all.

6. *Gahuni* (died 1860).—10 in all, together with a Cherokee-English vocabulary in Cherokee characters and other miscellany, contained in an unpaged blank book, 6 by 14 inches. Obtained in 1889 from his widow, Ayŭsta, mother of W. W. Long.

7. *Other formulas* originally written by Inâli ("Black Fox," died about 1880), Yânûgûlegi ("Climbing Bear," died 1904, Dûninâli ("Tracker," still living), Ayâsta ("Spoiler," died 1916), Âganstâta ("Groundhog Meat," still living), and others; mostly transcribed into No. 4.

8. A large number of dance songs, ceremonial addresses, Civil War letters from Cherokee in the Confederate service, council records, etc., all in the Cherokee language and characters, contained in various original blank book manuscripts and letter sheets. Some of these have been transcribed into No. 4, and many of them might properly appear with the Sacred Formulas.

Of all this material, about 150 formulas, including the entire Swimmer book, No. 2, were transliterated, translated, and annotated and glossarized, with Swimmer's assistance, in 1888–89. Of

these, 28 specimen formulas were published in 1891 in "Sacred Formulas of the Cherokees," in the Seventh Annual Report of the bureau. The manuscript glossary for the whole 150 formulas numbers about 2,000 words.

All the other formulas, together with the more important miscellany noted under No. 8, were transliterated and translated with interlinear translation in the summers of 1911–14, together with such additional explanation as might be furnished by surviving experts. Also some 500 or 600 plants noted in the medical prescriptions have been collected in the field, with their Cherokee names and uses, and the botanic identification made by assistance of the botanists of the National Museum. This entire body, exclusive of No. 2 completed, is now in process of final transcription and elaboration, with explanation, botanic appendix, and glossary. Most of the work at present is being devoted to the Gadigwanasti manuscript, but the interdependence of the formulas necessitates frequent shifting from one to another. The glossary proceeds incidentally with the final translation, but more slowly as the full import of the words becomes manifest. Many of the words and expressions are technical, symbolic, and in archaic and unusual dialectic forms, with corresponding difficulty of interpretation. The complete glossary will probably comprise at least 4,000 words.

The botanic section will consist of a list of all the plants used in the formulas, as stated, and of some others of special importance, with their Indian names and meanings, botanic identification, and Cherokee uses as deduced from the various formulas and from direct information.

An explanation of the method and significance of the ceremony, the preparation of the medicine and the manner of its application will accompany each formula, but this work is deferred to the end, to insure symmetrical treatment without unnecessary repetition.

It is planned to have one or more introductory chapters explanatory of the Cherokee mythology, beliefs relating to the spiritual and occult world, ceremonial observances, initiation of hunters, and other matters illustrative of the formulas, together with parallels from other tribal systems, and also a chapter explanatory of the peculiar linguistic forms.

More than 200 formulas have received final form. The finished work will fill at least one large report volume and require a year for completion.

In July and August, 1915, Mr. Mooney gave considerable time to furnishing information and suggestions for the proposed Sequoya statue intended to constitute Oklahoma's contribution to the Capitol gallery. The usual number of letter requests for miscellaneous information also received attention.

On May 27 Mr. Mooney proceeded to western North Carolina for the purpose of continuing his Cherokee studies, and at the close of the fiscal year was still in the field.

Dr. John R. Swanton, ethnologist, devoted the greater part of the year to his memoirs pertaining to the Creek and associated tribes, to which reference was made in the last report. The first of these, dealing with the habitat and classification of the former Southeastern Indians, their history and population, is nearly completed; it consists of upward of 750 typewritten pages, exclusive of the bibliography, all of which has been put in order and annotated. Some new manuscript sources of information have recently been discovered which will make further additions necessary, but with this exception the text is now complete. Six maps are to be used in illustration; two of these, which are entirely new, are now being made, and the others are to be reproductions. The second paper, to cover the social organization and social customs of the Creeks and their neighbors, has likewise been arranged and annotated, but it is being held in order to incorporate the results of further field research.

From the end of September until the latter part of November, 1915, Dr. Swanton was in Oklahoma, where he collected 113 pages of Natchez text from one of the three surviving speakers of the language; he also spent about three weeks among the Creek Indians, where about 80 pages of myths in English were procured. Further ethnological material was also obtained from the Creeks and from the Chickasaw, to whom a preliminary visit was made. While with the former people Dr. Swanton perfected arrangements with a young man to furnish texts in the native language, which he is able to write fluently, and in this way 173 pages have been submitted, not including translation. From Judge G. W. Grayson, of Eufaula, Okla., to whom the bureau has been constantly indebted in many ways, was obtained in Creek and English, and also in the form of a dictaphone record, a speech of the kind formerly delivered at the annual *poskita*, or busk, ceremony of the Creeks. From an Alibamu correspondent, referred to in previous reports, some additions to the Alibamu vocabulary and a few pages of Alibamu text were procured.

At the beginning of the fiscal year Mr. J. N. B. Hewitt, ethnologist, transcribed and edited the Seneca text "Dooä'dane'gē^{n}' and Hotkwisdadegě'^{n}'a; making 45 pages, to which he added a literal interlinear translation that required more than twice as many English words as Indian, the whole being equivalent to about 130 pages. This text is a part of the Seneca material now in press for the Thirty-second Annual Report of the bureau. Mr. Hewitt also read for correction, emendation, and expansion, the galley proofs of Curtin's Seneca material, and prepared more than 50 pages of notes and additions for the introduction and also for the text; he also has ready

notes and corrections for the proofs still to come. From unedited text Mr. Hewitt completed a free translation of 32 pages of the Onondaga version of the "requickening address" of the Ritual of Condolence of the League of the Iroquois, being a part of the material for his projected memoir on the Iroquois League.

After the material of the Seneca legends had been submitted for printing, Mr. Curtin's field records and notes, made while recording this material, came into possession of the bureau. Mr. Hewitt devoted much time to reading and examining this undigested material, some 4,000 pages, for the purpose of ascertaining whether part of it should be utilized for printing or for illustrative purposes in what was already in type. This examination yielded some good material for notes and interpretations, but only small return as to new material for printing.

In the early autumn Mr. Hewitt made special preparations for the prosecution of field work on his projected memoir on the League of the Iroquois, by tentative editing and copying of a number of Mohawk and Onondaga texts recorded hastily in the field in previous years. The following parts of the Ritual of the Condolence Council were thus typewritten: The fore part of the Ceremony of Condolence, called "Beside-The-Forest," or "Beside-The-Thicket," in Mohawk; the so-called "Requickening Address," in the Onondaga version, and also the explanatory "introduction" and the "reply" in Onondaga to the "Beside-The-Forest" address already noted; and the installation address in Onondaga, made by Dekanawida to the last two Seneca leaders to join the League, was likewise edited and typewritten. Mr. Hewitt also devoted much study to other parts of the League material, for the purpose of being able to discuss it intelligently and critically with native informants. Some of the most striking results of this year's field work are due to this preparatory study of the material already in hand. Mr. Hewitt spent many days in the office in searching out and preparing data for replies to correspondents of the bureau.

On April 17, 1916, Mr. Hewitt left Washington for the Six Nations reserve near Brantford, Ontario, for the purpose of resuming field work, having in view primarily the putting into final form of the Onondaga and Mohawk texts pertaining to the League of the Iroquois, recorded in former years. These texts cover a wide range of subjects and represent the first serious attempt to record in these languages very technical and highly figurative language from persons unaccustomed to dictate connected texts for recording. These text embody laws, decisions, rituals, ceremonies, and constitutional principles; hence it is essential that correct verbal and grammatic forms be given.

One of the most important results of Mr. Hewitt's field studies is the demonstration that, contrary to all available written records and various printed accounts, there were never more than 49 federal civil chiefs of the League of the Iroquois, and that the number 50, due to misconception of the meaning of ordinary terms by Thomas Webster of the New York Onondaga, who died about 30 years ago, is modern and unhistorical. This false teaching has gained credence because it arose only after the dissolution of the integrity of the League of the Iroquois in the years following its wars with the United States, when most of the tribes became divided, some removing to Canada and some remaining in New York State, a condition which naturally fostered new interpretations and newer versions of older legends and traditions.

Mr. Hewitt also recorded a Cayuga version of the so-called Dekanawida tradition, comprising 130 pages of text, dictated by Chief John H. Gibson, which purports to relate the events that led to the founding of the League or Confederation of the Five Iroquois tribes and the part taken therein by the principal actors. In this interesting version Dekanawida is known only by the epithet "The Fatherless," or literally "He Who is Fatherless," which emphasizes the prophecy that he would be born of a virgin. In this version "The Fatherless" is represented as establishing among the Cayuga tribesmen the exact form of government that later he founded among the Five Iroquois tribes. It is said that the Cayuga selfishly limited the scope of that form of government, and therefore its benefits, to the Cayuga people alone, for the Cayuga statesmen did not conceive of its applicability to the affairs and welfare of all men. And so, this tradition affirms, it became needful that "The Fatherless" return to the neighbor tribes of the Cayuga to establish among them the League of the Five Tribes of the Iroquois, which was designed to be shared by all the tribes of men. This event is mentioned in the other Dekanawida versions.

This Cayuga version also purports to explain the origin of the dualism lying at the foundation of all public institutions of Iroquois peoples, by attributing the first such organization among the Cayuga to two persons who were related to each other as "Father and Son," or "Mother and Daughter," and who agreed to conduct public affairs jointly. This statement of course is somewhat wide of the mark, because it does not explain the existence of similar dualisms among other tribes such dualisms resting commonly, in the social organization, on the dramatization of the relation of the male and female principles in nature.

Mr. Hewitt was also able to confirm another radical exegesis of a part of the installation ceremony of the League of the Iroquois as first proposed by himself. This deals with the significance and

the correct translation of the words of the famous "Six Songs" of this ceremony. All other interpreters who have attempted to translate these words have assumed that these songs are "songs of greeting and welcome," but Mr. Hewitt, solely on grammatic grounds and the position of these songs, regards them rather as "songs of parting," or "songs of farewell," which are dramatically sung by an impersonator for the dead chief or chiefs.

Mr. Hewitt also recorded, in the Onondaga dialect, a short legend descriptive of the three Air or Wind Beings or Gods, the so-called Hoñdu′′i, the patrons of the Wooden-mask or "False-face" Society, whose chief function is the exorcism of disease out of the community and out of the bodies of ill persons; another on the Medicine Flute; another on the Husk-mask Society; and another on the moccasin game used at the wake for a dead chief: in all more than 100 pages of text not related to the material dealing with the Iroquois League.

While in the field Mr. Hewitt purchased a number of fine specimens illustrating Iroquois culture, exhibiting art of a high order; these consist of a wooden mask, colored black; a husk-mask; two small drums; a "medicine" flute; a moccasin game used at a chief's wake; a pair of deer-hoof rattles; a horn rattle; and a squash rattle. During the time he was in the field, until the close of the fiscal year, Mr. Hewitt read, studied, corrected, and annotated about 8,000 lines of text other than that mentioned above, and also made a number of photographs of Indians.

Mr. Francis La Flesche, ethnologist, was engaged in assembling his notes on the rites of the Osage tribe. Up to the month of February, 280 pages of the ritual of the Fasting degree of the war rites were finished, completing that degree, which comprises 492 pages. The Çathadse, or Rush-mat degree, was next taken up and completed; this degree covers 104 pages. The Child-naming ritual was then commenced, and 21 pages have been finished.

In September, while on leave of absence, Mr. La Flesche was visited on the Omaha reservation by Xuthá Wato^{n}i^n of the Tsízhu Wano^n gens, who gave a description of the Washábe Athi^n, or war ceremony, as he remembered it. With this description he gave 5 wígie and 14 songs. The wígie and the words of the songs have been transcribed from the dictaphone but are not yet typewritten, and the music of the songs has not yet been transcribed. A number of stories also were obtained from Xuthá Wato^{n}i^n, among them that of the Osage traditional story of the separation of the Omaha and Osage tribes. Xuthá Wato^{n}i^n died soon after his return home, his death being regarded by many as confirming the old-time belief that anyone who recites informally the rituals associated with these ceremonies will inevitably suffer dire punishment. The death of this old

man shortly after giving the rituals has therefore added to the difficulties attending the task of recording these ancient rites.

Notwithstanding these obstacles, Mr. La Flesche succeeded, during his visit to the Osage Reservation in April and May, in securing from old Sho^n′gemo^{n}i^n the version of the Fasting ritual belonging to the Tsízhu Peace gens, of which he is a member. The wígie and the words of the songs have been transcribed from the dictaphone, but are not yet typewritten, and the music of the songs is also to be transcribed. Sho^n′gemo^{n}i^n likewise gave the Child-naming ritual belonging to his gens, in which there are two wígie, one containing 227 lines and the other 94. In addition to these rituals, Sho^n′gemo^{n}i^n, after considerable hesitancy, recounted the "Seven and Six" (13) coups he is always called on to recount when any No^n′ho^{n}zhi^{n}ga of the Ho^n′ga division performs the ceremonies of some of the war rites. For this service he is paid a horse and goods amounting in value from $125 to $150.

Mr. La Flesche also secured from Waxthízhi information concerning the duties of the two hereditary chiefs of the Osage tribe, the gentes from which they were chosen, and how their orders were enforced. He also obtained from Watśemo^{n}i^n two wígie, one recited by him at the ceremonies of the war rites, and the other by the Nó^{n}ho^{n}zhi^{n}ga of the Hó^{n}ga Ahiuto^n gens.

In these studies Mr. La Flesche was materially assisted by Washóshe and his wife, who have both overcome their aversion to telling of the rites. Washóshe resigned from the Nó^{n}ho^{n}zhi^{n}ga order because of the injustice of its members toward a woman whom he selected to weave ceremonially the rush-mat shrine for a waxobe when he was taking the Çathadse degree. This man presented to Mr. La Flesche a mnemonic stick owned by his father and gave the titles of the groups of lines marked on the stick, each of which represents a group of songs. This mnemonic stick will be placed in the National Museum with the Osage collection.

Mr. John P. Harrington, ethnologist, spent the entire fiscal year in making an exhaustive study of the Indians of the Chumashan linguistic stock of southern California. Three different bases have been established for working with informants and elaborating the notes. The period from July to October, inclusive, was spent at San Diego, Cal., where every facility for the work was granted by the courtesy of the Panama-California Exposition; November to March, inclusive, at the Southwest Museum, Los Angeles; and April to June, inclusive, at Santa Ynez. The month of January, 1916, was spent at Berkeley, Cal., where, through the courtesy of the Bancroft Library of the University of California, various linguistic manuscripts and historical archives pertaining to the Chumashan stock were studies and copied. During the period named more than

300,000 words of manuscript material were obtained and elaborated. In addition to the grammatical and ethnological material an exhaustive dictionary of the Ventureño is well under way, which comprises some 8,000 cards. This is to be followed by similar dictionaries for the other dialects. The most satisfactory feature of the work was the collection of material on the supposedly extinct dialects of San Luis Obispo and La Purísima. The Purisimeño material consists mainly of words and corrected vocabularies, while on the Obispeño important grammatical material was also obtained. A large part of the material which still remains to be obtained depends on the life of two very old informants, consequently it is most important that Mr. Harrington continue his work in this immediate field until the opportunities are exhausted.

The beginning of the fiscal year found Dr. Truman Michelson, ethnologist, at Tama, Iowa, engaged in continuing his researches among the Fox Indians, which consisted mainly of recording sociological data and ritualistic origin myths. In August, Dr. Michelson proceeded to Oklahoma for the purpose of investigating the sociology and phonetics of the Sauk Indians, as well as of obtaining translations of Fox texts pertaining especially to ritualistic origin myths. After successfully concluding this work, Dr. Michelson returned to Washington in October, when he commenced the translation of the textual material gathered in the field. Advantage was taken of the presence in Washington of a deputation of Piegan in obtaining a detailed knowledge of Piegan terms of relationship. From these studies Dr. Michelson determined that the lists of relationship terms recorded by Lewis H. Morgan, as well as by other investigators, require revision. He also commenced to arrange the material gathered by the late Dr. William Jones pertaining to the ethnology of the Ojibwa Tribe, with a view of its publication as a bulletin of the bureau. Toward the close of the year Dr. Michelson undertook to restore phonetically the text of the White Buffalo dance of the Fox Indians, which likewise is intended for bulletin publication. It is believed that the results of this task will be ready for the printer before the close of the calendar year.

Dr. Leo J. Frachtenberg, special ethnologist, divided his time, as in previous years, between field research and office work. On July 8 he left his winter headquarters at the United States training school at Chemawa, Oreg., and proceeded to the Yakima Reservation, Wash., where he revised, with the aid of the last Atfalati Indian, the Kalapuya manuscript material collected in 1877 by the late Dr. A. S. Gatschet of the bureau. This material, comprising 421 manuscript pages, consists of vocables, stems, grammatical forms, and ethnological and historical narratives, and its revision marked the comple-

tion of the work on the Kalapuya linguistic family commenced two summers ago. This work lasted until the latter part of July. In conjunction with this particular phase of field work, Dr. Frachtenberg corrected the second revision of the galley proofs of his Siuslaw grammatical sketch to appear in the second part of Bulletin 40.

On returning to Chemawa, Dr. Frachtenberg took up the editing and typewriting of his grammatical sketch of the Alsea language, the compilation of which was completed during the previous winter; this was finished in the early part of October, and the complete sketch, consisting of 158 sections and 421 typewritten pages, was submitted for publication in the second part of the Handbook of American Indian Languages (Bulletin 40). Dr. Frachtenberg interrupted this work on August 22 and took a short trip to the Siletz Reservation, where he collected 52 Athapascan and Shastan songs, which were transmitted to the bureau for future analysis.

On October 7 he proceeded to the Quileute Reservation, where he enlisted the services of a Quileute informant, with whom he returned to Chemawa and brought to a successful completion the study of the grammar and mythology of the Quileute Tribe. This investigation extended from October until the latter part of March. The material collected by Dr. Frachtenberg during this period consists of 30 native myths and traditions fully translated, a large body of notes to these texts, voluminous grammatical forms, and vocables. In January Dr. Frachtenberg left Chemawa for a short trip to the Grand Ronde Reservation, Oreg., where he recorded 19 Kalapuya songs on the dictaphone.

As Dr. Frachtenberg's allotment for field work among the Quileute was then exhausted, he was obliged to remain at Chemawa until the close of the fiscal year. He therefore undertook the correction of the page proofs of his grammatical sketch of the Siuslaw language (pp. 431–629), and on its completion engaged in translating, editing, and typewriting the Alsea texts collected in 1910. The editing of these texts involved much labor, since it was deemed advisable to present in the introduction a complete discussion of Alsea mythology, and a concordance beween the folklore of this tribe and the myths of the other tribes of the Pacific coast. For that purpose all the published works on the folklore of the tribes of the northwestern area were consulted, including that of the Maidu, Shasta, Yana, Klamath, Takelma, Coos, Lower Umpqua, Tillamook, Chinook, Kathlamet, Wishram, Quinault, Chilcotin, Shuswap, Thompson River, Lillooet, Haida, Tlingit, Kwakiutl, Tsimshian, Bellacoola, and the Athapascan Tribes of the north. This work was practically completed by the close of the fiscal year. The collection consists of 8 creation myths, 13 miscellaneous tales, 3 ethnological and historical narratives, 4 statements as to religious beliefs, and 3 tales collected in English (31

traditions in all). It comprises, in addition to the introdution, 392 typewritten pages, and will be submitted for publication as a bulletin of the bureau.

SPECIAL RESEARCHES.

Dr. Franz Boas, honorary philologist, continued his researches connected with the preparation of the remainder of part 2 of the Handbook of American Indian Languages, assisted by Dr. Hermann K. Haeberlin, Miss H. A. Andrews, and Miss Mildred Downs, and also devoted attention to the completion of the report on Tsimshian mythology.

The bulletin on "Kutenai Tales," for which galleys were received in July, 1915, has been revised twice and is nearing completion. The page proof is being extracted preparatory to the accompanying grammatical sketch and vocabulary.

Through the liberality of Mr. Homer E. Sargent, of Chicago, it has been possible to do much work on the preparation of an extended paper on the Salish dialects, now comprising about 500 pages of manuscript. The material has been collected since 1886, partly by Dr. Boas himself and partly by Mr. James Teit, the considerable expense of the field work of Mr. Teit having been generously met by Mr. Sargent. In the course of the last 30 years it has been possible to collect vocabularies of all the Salish dialects, sufficient to afford a clear insight into the fundamental relations of these dialects, a preliminary work necessary to a more thorough study of the language. At the same time Mr. Teit gathered ethnological notes which are to be included in this work. The preparation of the vocabularies and of the detailed comparison that had been begun in previous years by Dr. Boas has been continued by Dr. Haeberlin, the basis of this study being their manuscript material and the published sources. Also through the liberality of Mr. Sargent and in cooperation with Columbia University in the city of New York, Dr. Haeberlin will be able to supplement his material by an investigation of one of the tribes of Puget Sound.

The interest of Mr. Sargent has also made possible a detailed study of the Salish basketry of the interior plateau and the preparation of the illustrations for a memoir on this subject. For the latter purpose there have been utilized the collections of the United States National Museum, the American Museum of Natural History, the University Museum of Philadelphia, the Museum of the American Indian (Heye Foundation), and the private collections of Mr. Sargent and others.

The preparation of a manuscript on the Ethnology of the Kwakiutl Indians has been well advanced. The material for the first volume, which is to contain data collected by Mr. George Hunt, has been completed, excluding a number of translations which remain to be

elaborated. According to the plan, the work is to consist of two parts, the first a collection of data furnished by Mr. Hunt in answer to specific questions asked by Dr. Boas; the second a discussion of them, and other data collected on previous journeys to British Columbia. This volume is to consist of an account of the material culture, social organization, religion, and kindred subjects. Most of the illustrations for this volume have been completed, and about 1,600 pages of manuscript have been prepared. Miss Downs has made detailed extracts from Kwakiutl myths required for a discussion of this subject.

Miss Downs has also compared the proofs of Dr. Frachtenberg's Siuslaw grammar with published texts, and these proofs have been compared and passed on by Dr. Frachtenberg. This work completes the revision of the Siuslaw grammar, the publication of which has been delayed owing to various reasons.

No progress has been made toward the final publication of the Chukchee grammar, as it has been impossible to communicate with the author, Mr. W. Bogoras, who is in Russia.

Some progress has been made with the contributions to Mexican archeology and ethnology, to be edited by Prof. Alfred M. Tozzer, of Harvard University, with a view of their publication by the bureau as a bulletin. Dr. Paul Radin has furnished a manuscript on Huave; Dr. Haeberlin has nearly completed the study of modern Mexican tales, collected by Dr. Boas and by Miss Isabel Ramírez Castañeda; and Dr. Boas has been engaged in the preparation of material on certain types of Mexican pottery and on an account of a journey to Teul, Zacatecas.

Prof. W. H. Holmes, of the National Museum, completed for the bureau the preparation of part 1 of the Handbook of American Antiquities (Bulletin 60), and at the close of the year galley proofs of the entire work had been received and were in process of revision. On account of the pressure of more urgent work in connection with his official duties, only limited progress was made in the preparation of part 2. On April 21 Mr. Holmes made a brief visit to the museums of Philadelphia and New York for the purpose of conducting studies required in the preparation of this handbook.

Miss Frances Densmore's field trip during the summer of 1915 for the purpose of continuing her studies of Indian music, comprised visits to three reservations and occupied two and one-half months. Most of the time was spent among the Mandan and Hidatsa, at Fort Berthold, N. Dak., and during part of her sojourn Miss Densmore camped near what is recognized as the last Mandan settlement, where she was enabled to record many interesting data that could not have been obtained in any other way. The Indians felt more free to sing there than at the agency, and Miss Densmore also had an

opportunity to observe and photograph native customs, notably those of tanning a hide and preparing corn. The study of music on the Fort Berthold Reservation included that pertaining to the ceremony connected with eagle catching. An old eagle trap was visited and photographed, and the songs of the leader in the eagle camp were recorded by the only Mandan who had the hereditary right to sing them. The songs of the Goose Women Society and the Creek Women Society were also sung by those who inherited them and were recorded phonographically. Among these are the ceremonial songs sung by the "corn priest" in the spring to fructify the seed corn. Songs of war and of the various men's societies were also recorded. The total number of songs from this reservation now transcribed exceeds 100.

A new phase of the work was that of ascertaining the pitch discrimination of the Indians by means of tuning forks. This was begun at Fort Berthold and continued for comparative purposes at the Standing Rock and White Earth Reservations. Data from four tribes are now available on this subject of research.

Miss Densmore read all the galley and part of the page proofs of the bulletin on Teton Sioux Music. Important additions were made to this book in the form of graphic representations, original plots of 240 songs and 18 diagrams having been made to exhibit the results obtained through mathematical analyses. Of these graphic representations 63 will appear in the bulletin. One hundred and fifty pages of manuscript were submitted during the year, in addition to the descriptive analyses of the songs.

In the preparation of the Handbook of Aboriginal Remains East of the Mississippi, Mr. D. I. Bushnell, jr., added much new material. Many letters were sent to county officials in New England requesting information regarding the location of ancient village sites, burial places, and other traces of aboriginal occupancy in their respective areas. Many of the replies contained valuable and interesting information. Letters of like nature were addressed to officials in the Southern States, and the replies were equally satisfactory. Numerous photographs have been received from various sources, which will serve as illustrations for the handbook, but it is desired to increase the number if possible. The manuscript of the handbook will probably be completed during the next fiscal year.

Dr. Walter Hough, of the National Museum, was detailed to the bureau in June for the purpose of conducting archeological investigations in western central New Mexico. Proceeding to Luna, Socorro County, Dr. Hough commenced the excavation of a ruin previously located by him, as described in Bulletin 35 of the bureau (p. 59). This site was thought to contain evidence of pit dwellings exclusively, but excavations showed that an area of about 40 acres

contained circular, semisubterranean houses in which no stone was used for construction. Seven of the pits were cleared, and it was ascertained that many more existed beneath the surface, dug in the sandy substratum of the region. Burnt sections of roofing clay showed that these houses were roofed with beams, poles, brush, and mud, as in present pueblo construction. The roof was supported by wooden posts, charred remains of which were found. Nothing was ascertained respecting the construction of the sides of the dwellings or in regard to the height of the roofs. On the floor of each of the pits uncovered were a rude metate, grinding stones, slabs of stone, and the outline of an otherwise undefined fireplace not quite in the center of the chamber. A bench about a foot high and a few feet in length was cut in the wall of some of the pits, and in one of the pits, against the wall, was a fireplace with raised sides of clay.

Another type of structures adjoined the pits; these were rectangular, open-air houses with mud roofs, in which mealing and culinary work was carried on. Here were numerous metates, manos, rubbing stones, pottery, etc.; some of the metates were set up on three round stones. Near the pit was a cemetery in which infants were buried, the burials being associated with clay hearths and much charcoal, and near the bodies were placed small pottery vessels. Scrapers of flint and bones of deer were also found among the burials. So far as ascertained, the people who used the circular semisubterranean houses had a limited range. Traces of their culture have not been found below an elevation of 7,000 feet in the mountain valley, and it appears probable that their culture was associated with an environment of lakes which once existed in these valleys. It is evident in some cases that the pit dwellings were displaced by houses of stone. In most instances artifacts are different from those of the stone-house builders, and the latter have more points of resemblance to, than of difference from, the ancient inhabitants of Blue River. It is probable that the range of the pit-house people would be found to be more extensive by excavation around the sides of stone houses in other localities, the remains of pit structures being easily obliterated by natural filling. At this time the pit-dweller culture can be affiliated only with uncertainty with that of the ancient Pueblos. At the present stage of the investigation the lack of skeletal material is severely felt, but further work may overcome this difficulty.

In continuation of his preliminary examination of archeological remains in western Utah, summarized in the last annual report of the bureau (pp. 51–53), Mr. Neil M. Judd, of the National Museum, returned to Utah in June, 1916, and excavated one of the large mounds near Paragonah, in Iron County. Limited in time and handicapped by unfavorable weather, the results obtained were less than those anticipated; nevertheless they show the similarity existing

between the ancient Paragonah dwellings and those near Beaver City and neighboring settlements, and warrant the belief that the builders of these structures were more closely related to the house-building peoples of Arizona and New Mexico than has been suspected.

In the report following his reconnoissance of last year, Mr. Judd drew attention to the fact that the mounds still existing near Paragonah comprise a mere remnant of the large group formerly at that place and predicted the early razing of those remaining. The hurried investigation of this year was undertaken for the purpose of gaining information regarding these ruins before their destruction.

One of the largest and, at the same time, one of the least disturbed mounds was selected as a type for excavation. Its dimensions were approximately 100 by 300 feet; its average height was 4½ feet. Two great gashes had been made through the opposite ends of the mound by diggings of many years ago, each cut partially exposing the walls of a single long room. Including these two dwellings, which were reexcavated only with considerable difficulty, Mr. Judd successfully revealed and measured the walls of 14 rectangular houses, 11 of which are entirely cleared of fallen débris and earth accumulation. The walls of these ancient habitations, like those previously examined near Beaver City, had been constructed entirely of adobe mud; in their present condition they exhibited no evidence of the use of angular bricks or blocks similar to those employed in Pueblo structures subsequent to the Spanish conquest. On the contrary, close examination showed that the walls were invariably formed by the union of innumerable masses of plastic clay, forced together by the hands of the builders and surfaced inside and out during the process of construction. Careful inspection of the ruins showed that the dwellings were originally roofed in the manner typical of cliff houses and of modern Pueblo structures throughout the Southwest. No certain evidence could be found that doors or other wall openings were utilized by the primitive artisans—each house invariably consisted of a single room that apparently had been entered from the roof. One of the most important discoveries made during the course of the Paragonah excavations was that of a circular, semi-subterranean room which, with similar wall fragments previously discovered in the Beaver City mounds, tends to establish the use of the kiva, or ceremonial chamber, by the ancient house-building peoples of western Utah.

On the conclusion of his studies at Paragonah, Mr. Judd proceeded to Fillmore, Willard County, for the purpose of investigating certain mounds reported in that neighborhood. These and similar elevations near the villages of Meadow, Deseret, and Hinckley, were all superficially identified as of the same type and representing the same

degree of culture as those above described. In all a collection of more than 500 objects was gathered during the course of the season's work.

A pleasing coincidence resulting from Mr. Judd's Fillmore investigation was the fact that the guide he engaged had been employed in the same capacity by Dr. Edward Palmer, one of the National Museum's most indefatigable collectors, during the latter's expedition of 1872.

The archeological data collected by Mr. Judd during his two brief expeditions to western Utah are sufficient to warrant the extension of the northern limits of the area known to have been occupied by the ancient Pueblo peoples. Further work, however, is urgent, since that already accomplished has not only contributed certain valuable facts to Southwestern archeology, but it has shown also the probability of finding, in the unknown desert regions of that section, a solution of some of the vital questions with which American anthropology has labored for many years.

By reason of the fact that Mr. James R. Murie has been engaged by the American Museum of Natural History, New York City, in connection with its ethnologic researches pertaining to the Plains Indians, his work of recording the rites and ceremonies of the Pawnee Tribe came to a close, and tentative arrangements have been made whereby the American Museum will complete the investigation and the results published by the bureau. Dr. Clark Wissler, curator of anthropology of the American Museum, has undertaken this task.

Dr A. L. Kroeber, of the University of California, continued the preparation of the Handbook of the Indians of California for publication by the bureau, and at this writing it is believed that the manuscript, with the accompanying maps and illustrations, will be submitted for publication before the close of the calendar year.

MANUSCRIPTS.

The large collection of manuscripts in possession of the bureau was augmented by the following principal items, which do not include manuscripts in process of preparation by members of the bureau's staff for publication:

Miami-French dictionary; photostat copy of the original in the John Carter Brown Library at Providence, R. I.

A number of notebooks from Dr. A. L. Kroeber, on Gros Ventre and Cheyenne-Arapaho linguistics and texts. These consist of: (*a*) Gros Ventre, 41–47, 49; (*b*) Arapaho and Cheyenne, 1–14, 21–22, 24–28, and also a catalogue of this material recorded on 3,500 cards; (*c*) 110 pages of manuscript on the same subjects.

First draft of Gatschet's Klamath Dictionary, 177 pages.

Copies of the following manuscripts, made by photostat in the bureau by the courtesy of Rev. George Worpenberg, S. J., librarian of St. Mary's College, St. Marys, Kans.:

Catéchism dans la langue Potewatèmi, A. D. 1847.

Petit Catechism en Langue Potewatemi, A. D. 1848.

Evangelia Dom, and Evangelia in Festis, and portions of the Gospels read on Sundays and certain Festivals of the Saints.

PUBLICATIONS.

The task of editing the publications of the bureau has continued in charge of Mr. J. G. Gurley, editor, assisted from time to time by Mrs. Frances S. Nichols. Following is a summary for the year:

PUBLICATIONS ISSUED.

Twenty-ninth Annual Report (1907–08). Accompanying paper: The Ethnogeography of the Tewa Indians, by John Peabody Harrington.

Thirtieth Annual Report (1908–09). Accompanying papers: Ethnobotany of the Zuñi Indians (Stevenson); An Inquiry into the Animism and Folk-lore of the Guiana Indians (Roth).

Bulletin 57. An Introduction to the Study of the Maya Hieroglyphs (Morley).

Bulletin 62. Physical Anthropology of the Lenape or Delawares, and of the Eastern Indians in General (Hrdlička).

PUBLICATIONS IN PRESS OR IN PREPARATION.

Thirty-first Annual Report (1909–10). Accompanying paper: Tsimshian Mythology (Boas).

Thirty-second Annual Report (1910–11). Accompanying paper: Seneca Fiction, Legends, and Myths (collected by Jeremiah Curtin and J. N. B. Hewitt; edited by J. N. B. Hewitt).

Thirty-third Annual Report (1911–12). Accompanying papers: Designs on Prehistoric Hopi Pottery (Fewkes); Preliminary Account of the Antiquities of the Region between the Mancos and La Plata Rivers in Southwestern Colorado (Morris); Uses of Plants by the Indians of the Nebraska Region (Gilmore); Mound Excavation in the Eastern Maya Area, with an Introduction dealing with the General Culture of the Natives (Gann).

Bulletin 40. Handbook of American Indian Languages (Boas). Part 2.

Bulletin 55. Ethnobotany of the Tewa Indians (Robbins, Harrington, Freire-Marreco).

Bulletin 59. Kutenai Tales (Boas).

Bulletin 60. Handbook of Aboriginal American Antiquities, Part 1. Introductory. The Lithic Industries: Mining, Quarrying, Manufacture (Holmes).

Bulletin 61. Teton Sioux Music (Densmore).

The distribution of the publications of the bureau has continued in immediate charge of Miss Helen Munroe, of the Smithsonian Institution, and at times by Mr. E. L. Springer, assisted from the beginning of the fiscal year until his resignation on April 15 by Mr. W. A. Humphrey, and subsequently by Miss Lana V. Schelski. Notwithstanding conditions in Europe and the impossibility of sending publications abroad except to a very limited extent, 2,235 more pub-

lications were distributed than during the previous fiscal year. This distribution may be classified as follows:

Series.	Copies.
Annual reports and separates	2,036
Bulletins and separates	9,990
Contributions to North American Ethnology—volumes and separates	18
Introductions	9
Miscellaneous publications	367
	12,420

ILLUSTRATIONS.

Mr. DeLancey Gill, illustrator, has continued in charge of the preparation of the illustrations for the publications of the bureau and of photographing the members of visiting Indian deputations to Washington, in which work he has been assisted by Mr. Albert E. Sweeney. The results accomplished in this direction are as follows:

	Number.
Photographic prints for distribution and office use	1,137
Negatives of ethnologic and archeologic subjects	126
Negative films developed from field exposures	188
Photostat prints from books and manuscripts	1,125
Mounts used	78
Proofs examined	251
Photographs retouched	43
Drawings made	187
Portrait negatives of visiting delegations (Pawnee, Sauk and Fox, Winnebago, Blackfoot, Cheyenne, Chippewa)	25

The complete editions of three colored plates, aggregating 20,000 prints, were examined at the Government Printing Office. Illustrative material for three bulletins was completed for reproduction, and progress was made on similar work for the Thirty-third Annual Report.

LIBRARY.

The library of the bureau continued in charge of Miss Ella Leary, librarian, assisted by Charles B. Newman, messenger boy. During the year 1,078 volumes were accessioned; of these 214 were purchased, 135 were acquired by gift and exchange, and 729 are volumes of serials which were entered after having been bound for the first time. The library also procured 272 pamphlets, chiefly by gift. The periodicals currently received number about 750, of which 12 are acquired by subscription and 738 by exchange. Among the more noteworthy accessions of books are 20 volumes of Bibles, Testaments, and portions of the Bible in American Indian languages. The library now contains about 21,315 volumes, 13,460 pamphlets, and several thousand unbound periodicals. There were sent to the Government Printing Office for binding, 1,338 books, pamphlets, and

serial publications, and of these all but 20 had been returned to the bureau before the close of the year.

In addition to the cataloguing of current accessions the efforts of the librarian were devoted to making a subject, author, and analytical catalogue of the books represented in the old catalogue by an imperfect author catalogue alone. In this connection special attention was given to linguistic works. From time to time Mrs. F. S. Nichols has assisted in this work, and satisfactory progress has been made.

Although maintained primarily for the use of the staff, the library is consulted more and more by students not members of the bureau, as well as by officials of the Library of Congress and of the Government departments.

COLLECTIONS.

The following collections were acquired by the bureau, by members of its staff, or by those detailed in connection with its researches, and have been transferred to the National Museum:

704 archeological objects gathered in Utah and Wyoming by Mr. Neil M. Judd. (58757.)

Collection of potsherds showing types of ornamentation, from the Nacoochee Mound, White County, Georgia, being a part of the objects gathered by the joint expedition of the Bureau of American Ethnology and Museum of the American Indian (Heye Foundation). (58819.)

170 archeological specimens collected by Mr. Gerard Fowke at the flint quarry shop sites at Crescent, St. Louis County, Missouri. (59015.)

Collection of nonhuman bones from the Nacoochee Mound, Georgia. (59017.)

A small collection of prayer-sticks from a Pueblo shrine on the summit of Langley Peak, west of the Rio Grande and south of the Rio Chama, New Mexico, presented by Mr. Robert H. Chapman. (59112.)

53 Indian potsherds and arrow points presented by Mr. Arthur L. Norman, Troup, Texas. (59252.)

Stone "collar" from Porto Rico, received by purchase from Mr. K. A. Behne, San German, Porto Rico. (59280.)

A point and tackle of a salmon spear; a halibut hook, and five small fish-hooks, the gift of Mr. Robert H. Chapman. (59288.)

Set of ear perforators formerly owned by Wâthuxage of the Tsízhu Washtage gens of the Osage, presented through Mr. Francis La Flesche by Mrs. Fred Lookout. (59782.)

Sacred hawk bundle, or waxobe, of the Buffalo-face People of the Osage tribe, collected by Mr. Francis La Flesche. (59792.)

Osage war shield, collected by Mr. Francis La Flesche. (59934.)

PROPERTY.

In regard to the property of the bureau there is nothing to add to the statements presented in recent reports. The cost of necessary furniture, typewriters, and photographic and other apparatus acquired during the fiscal year was $238.54.

MISCELLANEOUS.

Quarters.—One of the rooms in the north tower occupied by the bureau force was repaired and painted, a new electric fixture installed, and the wooden casing under the exposed stairway removed and fireproofing substituted.

Personnel.—The only change in the personnel of the bureau was the resignation of Mr. William A. Humphrey, stenographer and typewriter, on April 15, 1916, and the appointment of Miss Lana V. Schelski on May 15 to fill the vacancy.

The correspondence and other clerical work of the office, in addition to that above mentioned, has been conducted by Miss Florence M. Poast, clerk to the ethnologist in charge; Miss May S. Clark, who particularly aided Mr. Bushnell in correspondence connected with the preparation of the Handbook of Aboriginal Remains; and Mrs. F. S. Nichols, who has aided the editor.

Respectfully submitted.

F. W. Hodge,
Ethnologist in Charge.

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution,
Washington, D. C.

APPENDIX 3.

REPORT ON THE INTERNATIONAL EXCHANGES.

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1916.

The congressional appropriation for the support of the service during the year, including the allotment for printing and binding, was $32,200 (the same amount as appropriated for the past eight years), and the repayments from departmental and other establishments aggregated $3,678.25, making the total available resources for carrying on the system of exchanges $35,878.25.

During the year 1916 the total number of packages handled was 301,625, an increase of 25,869, as compared with the preceding year. The weight of these packages was 399,695 pounds, an increase of 31,841 pounds.

Although these figures show an increase in the amount of work carried on by the service over that for last year, both the number and weight of the packages handled are lower than for the year 1914. This reduction, however, is accounted for by the suspension of shipments to a number of countries, owing to the European war, as explained in the last report.

The number and weight of the packages of different classes are indicated in the following table:

	Packages.		Weight.	
	Sent.	Received.	Sent.	Received.
			Pounds.	*Pounds.*
United States parliamentary documents sent abroad	161,265	....	93,458	....
Publications received in return for parliamentary documents	....	3,073	....	16,938
United States departmental documents sent abroad	72,766	....	142,415	....
Publications received in return for departmental documents	....	4,352	....	8,911
Miscellaneous scientific and literary publications sent abroad	42,862	....	84,196	....
Miscellaneous scientific and literary publications received from abroad for distribution in the United States	....	17,307	....	53,777
Total	276,893	24,732	320,069	79,626
Grand total	301,625		399,695	

In connection with the above statistics, attention should be called to the fact that many returns for publications sent abroad reach their destinations direct by mail and not through the Exchange Service.

Of the 1,758 boxes used in forwarding exchanges to foreign agencies for distribution, 319 contained full sets of United States official documents for authorized depositories, and 1,439 were filled with departmental and other publications for depositories of partial sets and for miscellaneous correspondents. The total number of boxes sent abroad during 1916 was 105 more than the preceding year.

As referred to last year, the interruption to transportation facilities caused by the European war made it necessary for the International Exchange Service in August, 1914, to suspend the shipment of consignments to Austria, Belgium, Bulgaria, Germany, Hungary, Montenegro, Roumania, Russia, Serbia, and Turkey. With the exception of Germany, exchange relations with these countries are still suspended. It has been possible to arrange for the sending of several consignments to Germany through the American consul general at Rotterdam, but the Institution has not yet undertaken the regular transmission of boxes to that country. One shipment has been received from Germany, and the Institution, through the Department of State, has arranged with the British Government for the sending of consignments from Germany to this country at bimonthly intervals.

In May, 1915, as mentioned in the last report, the Institution endeavored to arrange with the Commission of International Exchanges at Petrograd for the resumption of shipments to Russia by way of Archangel, but the commission then expressed a desire to postpone the renewal of operations until after the close of the war. The commission now writes that it has been found possible to resume the forwarding of consignments either by way of Vladivostok, Russia, or Bergen, Norway. The Institution has signified its preference for the latter route, at the same time asking if shipments can be forwarded to Russia through the same port.

Through the burning at sea of the steamship *Mount Eagle*, box 125, containing publications from various governmental and scientific establishments in this country for distribution in Korea, was destroyed. Owing to a similar accident to the steamship *Athenai*, box 231, for Greece, was lost. In almost every instance the Institution was able to procure from the senders duplicate copies of the lost publications, which were duly forwarded to their destinations. In this connection it should be stated that the destruction of the above-mentioned vessels was not due to the war. Thus far only two exchange packages—each containing 12 publications—have been lost

through the sinking of steamers by war vessels, reference to which was made in the last report.

In continuation of a policy of international helpfulness, the Institution has rendered aid to governmental and scientific establishments, both in this and foreign countries, in procuring especially desired publications. One instance in particular in which the Institution extended aid during the year in procuring publications may be referred to in this connection. The Pan American Division of the American Association for International Conciliation in New York City, which was assembling a library to consist of some seven or eight thousand volumes of works of North American origin for presentation to the Museo Social Argentino at Buenos Aires, applied, through the Department of State, for a selection of publications of the United States Government and of certain scientific institutions in this country. The matter was brought to the attention of the proper establishments, and several hundred publications were received for the proposed library. The Department of State, in bringing this matter to the attention of the Institution, stated that the department attached considerable importance to the request as a potent means of furthering the best ideals of Pan Americanism.

It may be stated in this connection that it is the custom of the Government of India to refer any requests from establishments in this country for Indian official documents to the Exchange Service for indorsement before acting thereon. In such instances statistics and other information relative to the society or establishment making the request is furnished, and a proper recommendation is made in regard to the application.

The number of boxes sent to each foreign country and the dates of transmission are shown in the following table:

Consignments of exchanges for foreign countries.

Country.	Number of boxes.	Date of transmission.
Argentina	51	July 21, Aug. 19, Sept. 30, Oct. 21, Nov. 26, 1915; Jan. 17, Feb. 18, Apr. 25, May 26, 1916.
Bolivia	6	July 16, Oct. 2, Nov. 12, Dec. 14, 1915; Feb. 3, Apr. 6, 1916.
Brazil	37	July 21, Aug. 19, Sept. 30, Oct. 21, Nov. 26, 1915; Jan. 17, Feb. 18, Mar. 25, May 26, 1916.
British Colonies	23	July 3, 10, 17, 24, 31, Aug. 7, 14, 21, 28, Sept. 4, 11, 18, 25, Oct. 9, 16, 23, 30, Nov. 6, 13, 20, 30, Dec. 4, 11, 18, 1915; Jan. 28, Feb. 8, 16, 25, Mar. 8, 20, Apr. 1, 10, 18, May 2, June 5, 16, 1916.
British Guiana	7	July 20, Aug. 20, Nov. 19, 1915; Feb. 5, Mar. 24, 1916.
Canada	24	Aug. 10, Oct. 23, Dec. 10, 1915; Feb. 25, Mar. 28, June 2, 1916.
Chile	23	July 21, Aug. 20, Oct. 4, Nov. 4, Dec. 3, 1915; Feb. 1, Mar. 2, Apr. 4, May 4, 1916.
China	53	July 14, Aug. 12, Sept. 24, Oct. 19, Nov. 27, Dec. 15, 1915; Jan. 8, 31, Feb. 23, Mar. 8, 24, Apr. 4, 7, 13, May 6, 1916.

Consignments of exchanges for foreign countries—Continued.

Country.	Number of boxes.	Date of transmission.
Colombia	11	July 16, Oct. 1, Nov. 12, Dec. 13, 1915.
Costa Rica	12	July 16, Oct. 2, Nov. 12, Dec. 13, 1915; Feb. 2, Mar. 3, Apr. 5, 1916.
Cuba	6	Aug. 10, Oct. 23, Dec. 10, 1915; Feb. 25, Mar. 28, June 2, 1916.
Denmark	33	July 2, Aug. 3, Sept. 9, Oct. 9, 28, Nov. 16, 30, 1915; Jan. 18, Mar. 17, June 10, 1916.
Ecuador	8	July 16, Aug. 17, Oct. 2, Nov. 12, Dec. 14, 1915; Mar. 4, Apr. 7, 1916.
Egypt	10	July 28, Aug. 24, Oct. 6, Nov. 9, Dec. 8, 1915; Feb. 5, May 26, 1916.
France	154	July 14, 29, Aug. 16, 26, Sept. 25, Oct. 14, Nov. 2, 18, Dec. 4, 1915; Jan. 28, Feb. 12, Mar. 14, Apr. 14, May 25, 1916.
Germany	137	Aug. 14, 1915; Jan. 19, June 9, 1916.
Great Britain and Ireland	392	July 3, 10, 17, 24, 31, Aug. 7, 14, 21, 28, Sept. 4, 11, 18, 25, Oct. 9, 16, 23, Nov. 6, 13, 20, 30, Dec. 4, 11, 18, 1915; Jan. 20, 28, Feb. 8, 16, 25, Mar. 8, 20, Apr. 1, 10, 17, May 2, June 5, 1916.
Greece	9	July 28, Aug. 28, Oct. 6, Nov. 12, Dec. 11, 1915; Jan. 25, 1916.
Guatemala	6	July 20, Oct. 6, Nov. 16, Dec. 14, 1915; Mar. 4, Apr. 6, 1916.
Haiti	6	Aug. 10, Oct. 23, Dec. 10, 1915; Feb. 25, Mar. 28, June 2, 1916.
Honduras	4	July 20, Oct. 6, 1915; Feb. 3, Apr. 6, 1916.
India	54	July 10, 17, 24, 31, Aug. 7, 14, 21, 28, Sept. 4, 11, 25, Oct. 9, 16, 23, 30, Nov. 6, 13, 20, 30, Dec. 4, 11, 18, 1915; Jan. 28, Feb. 8, 16, 25, Mar. 8, 20, Apr. 1, 10, 17, May 2, June 5, 16, 1916.
Italy	94	July 13, Aug. 25, Sept. 25, Oct. 13, Nov. 2, 18, Dec. 6, 1915; Jan. 21, Feb. 12, Mar. 14, Apr. 12, May 25, 1916.
Jamaica	6	July 29, Sept. 28, Nov. 5, Dec. 15, 1915; Feb. 4, Apr. 7, 1916.
Japan	50	July 5, Aug. 3, Sept. 11, Oct. 9, Nov. 9, Dec. 9, 1915; Jan. 29, Feb. 29, Mar. 29, Apr. 29, 1916.
Korea	3	July 28, Sept. 28, Oct. 23, 1915.
Liberia	3	July 29, Sept. 28, Dec. 15, 1915.
Lourenço Marquez	1	July 28, 1915.
Mexico	6	Aug. 10, Oct. 23, Dec. 10, 1915; Feb. 25, Mar. 28, June 2, 1916.
Netherlands	46	July 15, 27, Aug. 14, 17, 25, Sept. 28, Oct. 13, Nov. 3, Dec. 2, 1915; Jan. 21, Feb. 21, Apr. 1, May 2, 1916.
New South Wales	34	July 8, Aug. 10, Sept. 23, Oct. 20, Nov. 23, 1915; Jan. 14, Feb. 14, Mar. 15, Apr. 20, 1916.
New Zealand	28	July 13, Aug. 12, Sept. 24, Oct. 20, Nov. 23, 1915; Jan. 15, Feb. 14, Mar. 15, Apr. 21, 1916.
Nicaragua	4	July 20, Oct. 6, Nov. 16, 1915; Apr. 6, 1916.
Norway	26	July 2, Aug. 3, Sept. 9, Oct. 9, Nov. 9, Dec. 8, 1915; Jan. 25, Mar. 7, Apr. 17, 1916.
Paraguay	7	July 29, Oct. 2, Nov. 16, Dec. 14, 1915; Feb. 3, Apr. 7, 1916.
Peru	20	July 31, Aug. 20, Oct. 4, Dec. 3, 1915; Feb. 1, Mar. 2, Apr. 4, May 4, 1916.
Portugal	20	July 2, Aug. 3, Sept. 9, Oct. 9, Nov. 9, Dec. 8, 1915; Jan. 25, Mar. 7, Apr. 11, June 16, 1916.
Queensland	16	July 2, Aug. 12, Sept. 24. Oct. 20, Nov. 23, 1915; Jan. 15, Feb. 14, Mar. 15, Apr. 21, 1916.
Salvador	6	July 20, Oct. 6, Nov. 16, Dec. 14, 1915; Mar. 4, Apr. 6, 1916.
Siam	5	July 28, Sept. 28, Dec. 7, 1915; Apr. 7, Feb. 4, 1916.
South Australia	24	July 8, Aug. 10, Sept. 23, Oct. 20, Nov. 23, 1915; Jan. 14, Feb. 14, Mar. 15, Apr. 20, 1916.
Spain	40	July 7, Aug. 10, Sept. 22, Oct. 19, Dec. 2, 1915; Jan. 21, Feb. 21, Mar. 29, Apr. 28, June 10, 1916.

Consignments of exchanges for foreign countries—Continued.

Country.	Number of boxes.	Date of transmission.
Sweden	49	July 27, Aug. 24, Sept. 15, Oct. 18, Nov. 24, 1915; Jan. 15, Feb. 17, Mar. 17, Apr. 22, 1916.
Switzerland	50	Sept. 24, Oct. 13, Nov. 3, Dec. 3, 1915; Jan. 15, Feb. 18, Mar. 24, Apr. 24, June 8, 1916.
Tasmania	20	July 3, 10, 17, 24, 31, Aug. 7, 14, 21, 28, Sept. 4, 11, 18, 25, Oct. 9, 16, 30, Nov. 6, 13, 20, 30, Dec. 4, 11, 18 1915; Jan. 28, Feb. 8, 16, 25, Mar. 8, 20, Apr. 1, 10, 18, May 2, June 5, 16, 1916.
Trinidad	3	July 29, Sept. 28, Dec. 15, 1915.
Union of South Africa	34	July 27, Aug. 25, Nov. 5, Dec. 6, 1915; Feb. 5, Mar. 8, Apr. 11, 1916.
Uruguay	17	July 21, Aug. 20, Oct. 4, Nov. 12, Dec. 12, 1915; Feb. 2, Mar. 3, Apr. 5, 1916.
Venezuela	13	July 16, Oct. 2, Nov. 12, Dec. 13, 1915; Feb. 2, Mar. 8, Apr. 5, 1916.
Victoria	35	July 8, Aug. 10, 19, Sept. 21, Oct. 20, Nov. 23, 1915; Jan. 14, Feb. 14, Mar. 15, Apr. 20, 1916.
Western Australia	20	July 3, 10, 17, 24, 31, Aug. 7, 14, 21, 28, Sept. 4, 11, 18, 25, Oct. 9, 16, 23, 30, Nov. 6, 13, 20, 30, Dec. 4, 11, 18, 1915; Jan. 28, Feb. 8, 16, 25, Mar. 8, 20, Apr. 1, 10, 18, May 2, June 5, 16, 1916.
Windward and Leeward Islands.	2	July 29, Sept. 28, 1915.

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENTAL DOCUMENTS.

The number of sets of the United States official publications regularly forwarded to foreign countries in accordance with treaty stipulations and under the authority of the congressional resolutions of March 2, 1867, and March 2, 1901, has been reduced from 92 to 91—the series sent to the Government of Bombay having been discontinued at the latter's request. In asking that these shipments be discontinued, the secretary to the Government of Bombay stated that it would in no way affect the transmission of the reports of his Government for deposit in the Library of Congress.

The recipients of the 55 full and 36 partial sets are as follows:

DEPOSITORIES OF FULL SETS.

Argentina: Ministerio de Relaciones Exteriores, Buenos Aires.

Australia: Library of the Commonwealth Parliament, Melbourne.

Austria: K. K. Statistische Zentral-Kommission, Vienna.

Baden: Universitäts-Bibliothek, Freiburg. (Depository of the Grand Duchy of Baden.)

Bavaria: Königliche Hof- und Staats-Bibliothek, Munich.

Belgium: Bibliothèque Royale, Brussels.

Brazil: Bibliotheca Nacional, Rio de Janeiro.

Buenos Aires: Biblioteca de la Universidad Nacional de La Plata. (Depository of the Province of Buenos Aires.)

Canada: Library of Parliament, Ottawa.

CHILE: Biblioteca del Congreso Nacional, Santiago.

CHINA: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.

COLOMBIA: Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Secretaria de Estado (Asuntos Generales y Canje Internacional), Habana.

DENMARK: Kongelige Bibliotheket, Copenhagen.

ENGLAND: British Museum, London.

FRANCE: Bibliothèque Nationale, Paris.

GERMANY: Deutsche Reichstags-Bibliothek, Berlin.

GLASGOW: City Librarian, Mitchell Library, Glasgow.

GREECE: Bibliothèque Nationale, Athens.

HAITI: Secrétaire d'État des Relations Extérieures, Port au Prince.

HUNGARY: Hungarian House of Delegates, Budapest.

INDIA: Department of Education (Books), Government of India, Calcutta.

IRELAND: National Library of Ireland, Dublin.

ITALY: Biblioteca Nazionale Vittorio Emanuele, Rome.

JAPAN: Imperial Library of Japan, Tokyo.

LONDON: London School of Economics and Political Science. (Depository of the London County Council.)

MANITOBA: Provincial Library, Winnipeg.

MEXICO: Instituto Bibliográfico, Biblioteca Nacional, Mexico.

NETHERLANDS: Library of the States General, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: General Assembly Library, Wellington.

NORWAY: Storthingets Bibliothek, Christiania.

ONTARIO: Legislative Library, Toronto.

PARIS: Préfecture de la Seine.

PERU: Biblioteca Nacional, Lima.

PORTUGAL: Bibliotheca Nacional, Lisbon.

PRUSSIA: Königliche Bibliothek, Berlin.

QUEBEC: Library of the Legislature of the Province of Quebec, Quebec.

QUEENSLAND: Parliamentary Library, Brisbane.

RUSSIA: Imperial Public Library, Petrograd.

SAXONY: Königliche Oeffentliche Bibliothek, Dresden.

SERBIA: Section Administrative du Ministère des Affaires Étrangères, Belgrade.

SOUTH AUSTRALIA: Parliamentary Library, Adelaide.

SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.

SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Bibliothèque Fédérale, Berne.

TASMANIA: Parliamentary Library, Hobart.

TURKEY: Department of Public Instruction, Constantinople.

UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

VICTORIA: Public Library, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

WÜRTTEMBERG: Königliche Landesbibliothek, Stuttgart.

DEPOSITORIES OF PARTIAL SETS.

ALBERTA: Provincial Library, Edmonton.
ALSACE-LORRAINE: K. Ministerium für Elsass-Lothringen, Strassburg.
BOLIVIA: Ministerio de Colonización y Agricultura, La Paz.
BREMEN: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
BRITISH COLUMBIA: Legislative Library, Victoria.
BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
BULGARIA: Minister of Foreign Affairs, Sofia.
CEYLON: Colonial Secretary's Office (Record Department of the Library), Colombo.
ECUADOR: Biblioteca Nacional, Quito.
EGYPT: Bibliothèque Khédiviale, Cairo.
FINLAND: Chancery of Governor, Helsingfors.
GUATEMALA: Secretary of the Government, Guatemala.
HAMBURG: Senatskommission für die Reichs- und Auswärtigen Angelegenheiten.
HESSE: Grossherzogliche Hof-Bibliothek, Darmstadt.
HONDURAS: Secretary of the Government, Tegucigalpa.
JAMAICA: Colonial Secretary, Kingston.
LIBERIA: Department of State, Monrovia.
LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.
LÜBECK: President of the Senate.
MADRAS, PROVINCE OF: Chief Secretary to the Government of Madras, Public Department, Madras.
MALTA: Lieutenant Governor, Valetta.
MONTENEGRO: Ministère des Affaires Étrangères, Cetinje.
NEW BRUNSWICK: Legislative Library, Fredericton.
NEWFOUNDLAND: Colonial Secretary, St. Johns.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
NORTHWEST TERRITORIES: Government Library, Regina.
NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
PANAMA: Secretaria de Relaciones Exteriores, Panama.
PARAGUAY: Oficina General de Inmigracion, Asuncion.
PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.
ROUMANIA: Academia Romana, Bucharest.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SIAM: Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.
UNITED PROVINCES OF AGRA AND OUDH: Under Secretary to Government, Allahabad.
VIENNA: Bürgermeister der Haupt- und Residenz-Stadt.

INTERPARLIAMENTRY EXCHANGE OF OFFICIAL JOURNALS.

The Governments of Bolivia, Peru, and Venezuela were added to those countries with which the immediate exchange of official parliamentary journals is carried on. Following is a complete list of the Governments to which the Congressional Record is now sent:

Argentine Republic.
Australia.
Austria.
Baden.
Belgium.
Bolivia.
Brazil.
Buenos Aires, Province of.
Canada.
Costa Rica.

Cuba.
Denmark.
France.
Great Britain.
Greece.
Guatemala.
Honduras.
Hungary.
Italy.
Liberia.
New South Wales.
New Zealand.
Peru.
Portugal.
Prussia.
Queensland.
Roumania.
Russia.
Serbia.
Spain.
Switzerland.
Transvaal.
Union of South Africa.
Uruguay.
Venezuela.
Western Australia.

It will therefore be seen that there are now 36 countries with which this exchange is conducted. To some of these countries two copies of the Congressional Record are sent—one to the Upper and one to the Lower House of Parliament—the total number transmitted being 41.

LIST OF BUREAUS OR AGENCIES THROUGH WHICH EXCHANGES ARE TRANSMITTED.

The following is a list of the bureaus or agencies through which exchanges are transmitted:

ALGERIA, *via* France.

ANGOLA, *via* Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Santa Fé 880, Buenos Aires.

AUSTRIA: K. K. Statistische Zentral-Kommission, Vienna.

AZORES, *via* Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Rue des Longs-Chariots 46, Brussels.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

BRITISH COLONIES: Crown Agents for the Colonies, London.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANARY ISLANDS, *via* Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

DENMARK: Kongelige Danske Videnskabernes Selskab, Copenhagen.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Government Publications Office, Printing Department, Cairo.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Berlin, N. W. 7.
GREAT BRITAIN AND IRELAND: Messrs. William Wesley & Son, 28 Essex Street, Strand, London.
GREECE: Bibliothèque Nationale, Athens.
GREENLAND, *via* Denmark.
GUADELOUPE, *via* France.
GUATEMALA: Instituto Nacional de Varones, Guatemala.
GUINEA, *via* Portugal.
HAITI: Secrétaire d'État des Relations Extérieures, Port au Prince.
HONDURAS: Biblioteca Nacional, Tegucigalpa.
HUNGARY: Dr. Julius Pikler, Municipal Office of Statistics, Váci-utca 80, Budapest.
ICELAND, *via* Denmark.
INDIA: India Store Department, India Office, London.
ITALY: Ufficio degli Scambi Internazionali, Biblioteca Nazionale Vittorio Emanuele, Rome.
JAMAICA: Institute of Jamaica, Kingston.
JAPAN: Imperial Library of Japan, Tokyo.
JAVA, *via* Netherlands.
KOREA: Government General, Keijo.
LIBERIA: Bureau of Exchanges, Department of State, Monrovia.
LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.
LUXEMBURG, *via* Germany.
MADAGASCAR, *via* France.
MADEIRA, *via* Portugal.
MONTENEGRO: Ministère des Affaires Étrangères, Cetinje.
MOZAMBIQUE, *via* Portugal.
NETHERLANDS: Bureau Scientifique Central Néerlandais, Bibliothèque de l'Université, Leyden.
NEW GUINEA, *via* Netherlands.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: Dominion Museum, Wellington.
NICARAGUA: Ministerio de Relaciones Exteriores, Managua.
NORWAY: Kongelige Norske Frederiks Universitet Bibliotheket, Christiania.
PANAMA: Secretaria de Relaciones Exteriores, Panama.
PARAGUAY: Servicio de Canje Internacional de Publicaciones, Sección Consular y de Comercio, Ministerio de Relaciones Exteriores, Asuncion.
PERSIA: Board of Foreign Missions of the Presbyterian Church, New York City.
PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
PORTUGAL: Serviço de Permutações Internacionaes, Inspecção Geral das Bibliothecas e Archivos Publicos, Lisbon.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
ROUMANIA: Academia Romana, Bucharest.
RUSSIA: Commission Russe des Échanges Internationaux, Bibliothèque Imperiale Publique, Petrograd.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SERBIA: Section Administrative du Ministère des Affaires Étrangères, Belgrade.
SIAM: Department of Foreign Affairs, Bangkok.
SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.
SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.

SUMATRA, *via* Netherlands.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service des Échanges Internationaux, Bibliothèque Fédérale Centrale, Berne.
SYRIA: Board of Foreign Missions of the Presbyterian Church, New York.
TASMANIA: Secretary to the Premier, Hobart.
TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
TUNIS, *via* France.
TURKEY: American Board of Commissioners for Foreign Missions, Boston.
UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
WINDWARD AND LEEWARD ISLANDS: Imperial Department of Agriculture, Bridgetown, Barbados.

Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk, International Exchange Service.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

AUGUST 23, 1916.

Appendix 4.

REPORT ON THE NATIONAL ZOOLOGICAL PARK.

Sir: I have the honor to present below a report concerning the operations of the National Zoological Park for the fiscal year ending June 30, 1916.

There was allowed by Congress the sum of $100,000 for all purposes, except printing, for which $200 additional was granted.

The European war has had a marked effect upon the cost of living animals. Not only are the prices higher, but transportation is more difficult and therefore more expensive. Many of the regular dealers have been obliged to withdraw from the business. Notwithstanding these difficulties the National Zoological Park has maintained its collection fairly well, and remains at about the same level in numbers as last year. There are, indeed, some 15 species in the park not previously exhibited here. A careful estimate of the value of the animals in the collection shows that it must be at least $90,000, at the prevailing market prices. The value of the buildings is estimated at $210,000.

ACCESSIONS.

Births, 101 in number, included 5 American bison, deer of 11 species, a yak, a South American tapir, a Bactrian camel, 2 monkeys, some other mammals, and a few birds.

Gifts.—The most important of these was four elands and four Kashmir deer received from the Duke of Bedford at Woburn Abbey, England. Three fawns were born from the deer during their transit. The complete list of the donors and gifts is as follows:

Mr. Edward Anderson, jr., Tucson, Ariz., a desert lynx.

Miss Maude Anderson, Washington, D. C., a common canary.

Miss Marian Ashby, Washington, D. C., a barred owl.

Mr. O. E. Baynard, Clearwater, Fla., two barred owls.

The Duke of Bedford, Woburn Abbey, England, four elands and four Kashmir deer.

Bureau of Biological Survey, an American marten.

Mr. Robert Burrows, Washington, D. C., two alligators.

Miss Argine Carusi, Washington, D. C., an alligator.

Mr. Austin M. Cooper, Washington, D. C., a tarantula.

Mr. E. J. Court, Washington, D. C., a great horned owl.

Mr. Blaine Elkins, Washington, D. C., two raccoons.

Mr. W. C. Emery, Washington, D. C., a copperhead snake.

Mr. Victor J. Evans, Washington, D. C., three marmosettes.
Mr. George Field, Washington, D. C., a Texan armadillo.
Mr. Marcus A. Hanna, Washington, D. C., a copperhead snake.
Mr. G. M. Haynes, Washington, D. C., an alligator.
Mr. Ross Hazeltine, United States Consular Service, an ocelot.
Mrs. Mary F. Henderson, Washington, D. C., two grass parrakeets and a canary.
Mrs. Robert Hitt, Washington, D. C., a bare-eyed cockatoo.
Mr. G. C. Hogan, Comorn, Va., a gray fox.
Mr. George Howell, Washington, D. C., two alligators.
Mr. R. C. Huey, Hot Springs, Ark., a dusky wolf.
Miss Juergens, Washington, D. C., an alligator.
Miss Annie Lee Knight, Washington, D. C., a gray fox.
Mr. J. C. Lamon, Knoxville, Tenn., a black snake.
Mr. T. P. Lovering, Washington, D. C., a king snake.
Mr. S. Lyons, Washington, D. C., two alligators.
Mr. Vinson McLean, Washington, D. C., a gray parrot, a macaw, and a great red-crested cockatoo.
Mr. Lee S. Page, Washington, D. C., an alligator.
Hon. Frank Park, M. C., Sylvester, Ga., at request of late Senator Bacon, three fox squirrels.
Mr. Robert Portner, Washington, D. C., an alligator.
Mr. C. S. Rockwood, Washington, D. C., an alligator.
Mr. Baynard Schindel, Washington, D. C., an alligator.
Dr. R. W. Shufeldt, Washington, D. C., a black snake.
Mr. J. H. Steig, Washington, D. C., a black snake.
Dr. J. R. Stewart, Washington, D. C., a woodchuck.
Mrs. F. H. Talkes, Washington, D. C., a parrot.
Mrs. R. B. Tingsley, Washington, D. C., an alligator.
Mr. C. V. R. Townsend, Munising, Mich., a coyote.
Hon. Woodrow Wilson, Washington, D. C., two bald eagles.
Unknown donor, an alligator.
Unknown donor, two cardinals, one common mocking bird, one brown thrasher.

Exchanges.—The possession of a considerable number of surplus animals made it possible for the park to profit by 187 exchanges. Among the important acquisitions were a pair of young lions from the Department of Parks, New York City, a male guanaco from the Philadelphia Zoological Garden, a chimpanzee, a fine pair of Siberian tigers, a nilgai, a pair of mule deer, a pair of Columbian black-tailed deer, a great red kangaroo, several monkeys and other mammals, a secretary vulture, and a considerable number of other birds.

The chimpanzee was new to the collection and is a very intelligent and interesting male about 4½ years old, from the forests of French Congo. He is an object of great interest to the public and attracts much attention every day, especially when at his meals, as he has been taught to sit in a chair at a table, eat with a fork and drink out of a glass. As there was no conveniently available cage for him in the monkey house, special quarters have been provided in the lion house, in a corner where he is shielded from drafts of air. In

order to prevent feeding by visitors a glass screen was erected between this cage and the public space. Pure air is provided by a duct leading from the outside of the building suitably warmed by a heating coil. He has made himself entirely at home there, appears happy, contented, and quite healthy. A larger, more spacious cage will be constructed for occupation during hot weather, where he can be more satisfactorily seen.

From Yellowstone National Park.—Two black timber wolves, interesting from their rarity, were transferred from the Yellowstone Park.

Captured.—A raccoon, possibly a wild one, but more probably one that had escaped, was caught in a trap.

Loaned.—3 mink and 7 martens were temporarily loaned, also 1 monkey and a parrot.

LOSSES.

Among the most important losses was that of the young male African elephant, Jumbo II, a beautiful, active animal that was bought from the Government Zoological Garden at Giza, Egypt, in 1913. He was then about 4 years old. The death of this valuable animal was entirely unexpected, as he had always seemed in excellent health. A post-mortem examination, made by veterinarians from the Bureau of Animal Industry, revealed a rupture of the stomach, a tear 7 inches in length occurring along the great curvature. Escape of the stomach contents had caused an acute peritonitis. The cause of this rupture is quite obscure. The diet of the animal had not been changed either in quantity or quality, and the stomach had not been overdistended by food. Nor did an examination of the discharged material reveal any substances that might have occasioned an active fermentation with considerable evolution of gas. The other viscera showed no gross pathologic changes.

Other losses were a male lion, from softening of the brain, a fur seal, a male California sea lion, a black leopard, from old age, a male American bison, from pneumonia, a male and female nilgai, from generalized tuberculosis; 38 animals were lost from attacks by cage mates, by dogs (directly or indirectly), or through other accidents. Amebic dysentery attacked some spider monkeys, recently received, and caused the death of six of these animals. Post-mortem examinations were made, as usual, by the Pathological Division of the Bureau of Animal Industry, Department of Agriculture.[1]

[1] The causes of death were reported to be as follows: Enteritis, 24; gastroenteritis, 4; amebic dysentery, 6; fermentation colic, 1; intestinal coccidiosis, 1; cercomoniasis, 1; pneumonia, 15; tuberculosis, 14; congestion of lungs, 3; pulmonary edema, 1; asthma, 1; aspergillosis, 4; pyemia, 3; septicemia, 1; toxemia, 1; pericarditis, 1; hepatitis, 2; fatty degeneration of kidneys, 1; gangrene of cecum, 1; necrosis of rectum, 1; softening of brain, 1; hematoma of liver, 1; tumor, 1; anemia, 2; rupture of stomach, 1; no sufficient cause found, 17; not fit for examination, 3.

ANIMALS IN THE COLLECTION JUNE 30, 1916.

MAMMALS.

Chimpanzee (*Pan troglodytes*)	1
Mona monkey (*Cercopithecus mona*)	3
Patas monkey (*Cercopithecus patas*)	2
Diana monkey (*Cercopithecus diana*)	1
Bonnet monkey (*Macacus sinicus*)	1
Macaque monkey (*Macacus cynomolgus*)	2
Pig-tailed monkey (*Macacus nemestrinus*)	3
Rhesus monkey (*Macacus rhesus*)	20
Brown macaque (*Macacus arctoides*)	2
Japanese monkey (*Macacus fuscatus*)	3
Moor macaque (*Macacus maurus*)	1
Chacma (*Papio porcarius*)	1
Guinea baboon (*Papio papio*)	4
Yellow baboon (*Papio cynocephalus*)	1
Hamadryas baboon (*Papio hamadryas*)	2
Mandrill (*Papio sphinx*)	1
White-throated capuchin (*Cebus hypoleucus*)	2
Brown capuchin (*Cebus fatuellus*)	1
Gray spider-monkey (*Ateles geoffroyi*)	5
Marmosette (*Hapale jacchus*)	3
Mongoose lemur (*Lemur mongoz*)	1
Black lemur (*Lemur macaco*)	1
Polar bear (*Thalarctos maritimus*)	2
European brown bear (*Ursus arctos*)	2
Kadiak bear (*Ursus middendorffi*)	1
Yakutat bear (*Ursus dalli*)	1
Alaskan brown bear (*Ursus gyas*)	2
Kidder's bear (*Ursus kidderi*)	2
Hybrid bear (*Ursus kidderi-arctos*)	2
Himalayan bear (*Ursus thibetanus*)	1
Japanese bear (*Ursus japonicus*)	1
Grizzly bear (*Ursus horribilis*)	3
Black bear (*Ursus americanus*)	6
Cinnamon bear (*Ursus americanus*)	2
Sloth bear (*Melursus ursinus*)	1
Kinkajou (*Cercoleptes caudivolvulus*)	1
Cacomistle (*Bassariscus astuta*)	1
Gray coatimundi (*Nasua narica*)	4
Raccoon (*Procyon lotor*)	13
American badger (*Taxidea taxus*)	2
European badger (*Meles taxus*)	2
Common skunk (*Mephitis putida*)	2
Tayra (*Galictis barbara*)	1
American marten (*Mustela americana*)	9
Fisher (*Mustela pennantii*)	1
Mink (*Putorius vison*)	8
Common ferret (*Putorius putorius*)	1
North American otter (*Lutra canadensis*)	5
Eskimo dog (*Canis familiaris*)	4
Dingo (*Canis dingo*)	1
Gray wolf (*Canis occidentalis*)	6
Dusky wolf (*Canis nubilus*)	1
Coyote (*Canis latrans*)	3
Woodhouse's coyote (*Canis frustror*)	2
Red fox (*Vulpes pennsylvanicus*)	4
Swift fox (*Vulpes velox*)	1
Arctic fox (*Vulpes lagopus*)	1
Gray fox (*Urocyon cinereo-argenteus*)	5
Spotted hyena (*Hyæna crocuta*)	1
African civet (*Viverra civetta*)	1
Common genet (*Genetta genetta*)	1
Cheetah (*Cynailurus jubatus*)	2
Sudan lion (*Felis leo*)	5
Bengal tiger (*Felis tigris*)	2
Siberian tiger (*Felis tigris longipilis*)	2
Puma (*Felis oregonensis hippolestes*)	4
Jaguar (*Felis onca*)	1
Leopard (*Felis pardus*)	3
Ocelot (*Felis pardalis*)	1
Canada lynx (*Lynx canadensis*)	3
Bay lynx (*Lynx rufus*)	7
Spotted lynx (*Lynx rufus texensis*)	2
California lynx (*Lynx rufus californicus*)	1
Florida lynx (*Lynx rufus floridanus*)	1
Steller's sea lion (*Eumetopias stelleri*)	1
California sea lion (*Zalophus californianus*)	1
Harbor seal (*Phoca vitulina*)	1
Fox squirrel (*Sciurus niger*)	9
Western fox squirrel (*Sciurus ludovicianus*)	11
Gray squirrel (*Sciurus carolinensis*)	40
Black squirrel (*Sciurus carolinensis*)	20
Albino squirrel (*Sciurus carolinensis*)	1
Thirteen-lined spermophile (*Spermophilus tridecimlineatus*)	2
Prairie dog (*Cynomys ludovicianus*)	9
Woodchuck (*Marmota monax*)	1
American beaver (*Castor canadensis*)	2
Coypu (*Myocastor coypus*)	2
European porcupine (*Hystrix cristata*)	3
Indian porcupine (*Hystrix leucura*)	1
Viscacha (*Lagostomus trichodactylus*)	1
Mexican agouti (*Dasyprocta mexicana*)	1
Azara's agouti (*Dasyprocta azaræ*)	1
Crested agouti (*Dasyprocta cristata*)	2
Hairy-rumped agouti (*Dasyprocta prymnolopha*)	4
Paca (*Cœlogenys paca*)	2
Guinea pig (*Cavia cutleri*)	13
Patagonian cavy (*Dolichotis patagonica*)	2
Cottontail rabbit (*Lepus sylvaticus*)	2
Domestic rabbit (*Lepus cuniculus*)	15
African elephant (*Elephas oxyotis*)	1
Indian elephant (*Elephas maximus*)	1
Brazilian tapir (*Tapirus americanus*)	4
Mongolian horse (*Equus przewalskii*)	1
Grevy's zebra (*Equus grevyi*)	2
Zebra-horse hybrid (*Equus grevyi-caballus*)	1
Zebra-donkey hybrid (*Equus grevyi-asinus*)	1
Grant's zebra (*Equus burchelli granti*)	1
Collared peccary (*Dicotyles angulatus*)	2
Wild boar (*Sus scrofa*)	1
Northern wart-hog (*Phacochœrus africanus*)	2
Hippopotamus (*Hippopotamus amphibius*)	2
Guanaco (*Lama huanachus*)	3
Llama (*Lama glama*)	8
Alpaca (*Lama pacos*)	2
Vicugna (*Lama vicugna*)	1
Bactrian camel (*Camelus bactrianus*)	3
Arabian camel (*Camelus dromedarius*)	4
Sambar deer (*Cervus unicolor*)	2
Philippine deer (*Cervus philippinus*)	1
Hog deer (*Cervus porcinus*)	9
Barasingha deer (*Cervus duvaucelii*)	13
Axis deer (*Cervus axis*)	8
Japanese deer (*Cervus sika*)	6
Kashmir deer (*Cervus cashmirianus*)	7
Red deer (*Cervus elaphus*)	10
American elk (*Cervus canadensis*)	8
Fallow deer (*Cervus dama*)	7
Virginia deer (*Odocoileus virginianus*)	13
Mule deer (*Odocoileus hemionus*)	4
Columbian black-tailed deer (*Odocoileus columbianus*)	5
Cuban deer (*Odocoileus sp.*)	1
Blesbok (*Damaliscus albifrons*)	1
White-tailed gnu (*Connochætes gnu*)	1
Defassa water buck (*Cobus defassa*)	1
Indian antelope (*Antilope cervicapra*)	4
Arabian gazelle (*Gazella arabica*)	2
Sable antelope (*Hippotragus niger*)	1
Nilgai (*Boselaphus tragocamelus*)	2
Congo harnessed antelope (*Tragelaphus gratus*)	2
Eland (*Taurotragus oryx livingstonii*)	4

Tahr (*Hemitragus jemlaicus*)	3
Circassian goat (*Capra hircus*)	4
Barbary sheep (*Ovis tragelaphus*)	12
Barbados sheep (*Ovis aries-tragelaphus*)	8
Anoa (*Anoa depressicornis*)	1
Zebu (*Bibos indicus*)	2
Yak (*Poephagus grunniens*)	4
American bison (*Bison americanus*)	17
Hairy armadillo (*Dasypus villosus*)	3
Great gray kangaroo (*Macropus giganteus*)	1
Wallaroo (*Macropus robustus*)	2
Red kangaroo (*Macropus rufus*)	3
Bennett's wallaby (*Macropus ruficollis bennetti*)	1
Phalanger (*Trichosurus vulpecula*)	2
Virginia opossum (*Didelphys marsupialis*)	1

BIRDS.

Mocking bird (*Mimus polyglottos*)	1
Catbird (*Dumetella carolinensis*)	1
Brown thrasher (*Toxostoma rufum*)	1
Japanese robin (*Liothrix luteus*)	5
Laughing thrush (*Garrulax leucolophus*)	2
Australian gray jumper (*Struthidea cinerea*)	2
Bishop finch (*Tanagra episcopus*)	4
Cut-throat finch (*Amadina fasciata*)	2
Zebra finch (*Amadina castanotis*)	4
Black-headed finch (*Munia atricapilla*)	4
Three-colored finch (*Munia malacca*)	6
White-headed finch (*Munia maja*)	9
Nutmeg finch (*Munia punctularia*)	6
Java sparrow (*Munia oryzivora*)	12
White Java sparrow (*Munia oryzivora*)	14
Black-faced Gouldian finch (*Poëphila gouldiæ*)	2
Red-faced Gouldian finch (*Poëphila mirabilis*)	2
Sharp-tailed grass finch (*Poëphila acuticauda*)	1
Chestnut-breasted finch (*Donacola castaneothorax*)	6
Napoleon weaver (*Pyromelana afra*)	4
Madagascar weaver (*Foudia madagascariensis*)	4
Red-billed weaver (*Quelea quelea*)	8
Paradise weaver (*Vidua paradisea*)	8
Red-crested cardinal (*Paroaria cucullata*)	2
Common cardinal (*Cardinalis cardinalis*)	4
Saffron finch (*Sycalis flaveola*)	15
Yellow hammer (*Emberiza citrinella*)	1
Common canary (*Serinus canarius*)	7
Cowbird (*Molothrus ater*)	1
Glossy starling (*Lamprotornis caudatus*)	1
European raven (*Corvus corax*)	1
Australian crow (*Corvus coronoides*)	1
White-throated jay (*Garrulus leucotis*)	1
Blue jay (*Cyanocitta cristata*)	1
American magpie (*Pica pica hudsonica*)	3
Red-billed magpie (*Urocissa occipitalis*)	1
Yellow tyrant (*Pitangus sulphuratus rufipennis*)	1
Giant kingfisher (*Dacelo gigas*)	2
Concave-casqued hornbill (*Dichoceros bicornis*)	1
Reddish motmot (*Momotus subrufescens*)	1
Yellow-breasted lory	1
Blue Mountain lory (*Trichoglossus novæ-hollandiæ*)	8
Scaly-breasted lorikeet (*Psitteuteles chlorolepidotus*)	7
Sulphur-crested cockatoo (*Cacatua galerita*)	8
White cockatoo (*Cacatua alba*)	8
Great red-crested cockatoo (*Cacatua moluccensis*)	1
Leadbeater's cockatoo (*Cacatua leadbeateri*)	1
Bare-eyed cockatoo (*Cacatua gymnopis*)	3
Roseate cockatoo (*Cacatua roseicapilla*)	12
Yellow and blue macaw (*Ara ararauna*)	2
Red and yellow and blue macaw (*Ara macao*)	7
Red and blue macaw (*Ara chloroptera*)	2
Gray-breasted parrakeet (*Myopsittacus monachus*)	1
Cuban parrot (*Amazona leucocephala*)	1
Festive amazon (*Amazona festiva*)	1
Porto Rican amazon (*Amazona vittata*)	1
Yellow-shouldered amazon (*Amazona ochroptera*)	2
Yellow-fronted amazon (*Amazona ochrocephala*)	2
Yellow-naped amazon (*Amazona auripalliata*)	2
Yellow-headed amazon (*Amazona levaillanti*)	2
Blue-fronted amazon (*Amazona æstiva*)	1
Gray parrot (*Psittacus erythacus*)	1
Lesser vasa parrot (*Coracopsis nigra*)	1
Banded parrakeet (*Palæornis fasciata*)	1
Love bird (*Agapornis pullaria*)	1
Shell parrakeet (*Melopsittacus undulatus*)	6
Great horned owl (*Bubo virginianus*)	14
Arctic horned owl (*Bubo virginianus subarcticus*)	1
Barred owl (*Strix varia*)	4
Sparrow hawk (*Falco sparverius*)	2
Bald eagle (*Haliæetus leucocephalus*)	15
Alaskan bald eagle (*Haliæetus leucocephalus alascanus*)	1
Golden eagle (*Aquila chrysaëtos*)	2
Australian eagle	2
Harpy eagle (*Thrasaëtus harpyia*)	1
Crowned hawk-eagle (*Spizaëtus coronatus*)	1
Cooper's hawk (*Accipiter cooperi*)	1
Venezuelan hawk	1
Caracara (*Polyborus cheriway*)	3
Lammergeyer (*Gypaëtus barbatus*)	1
Secretary vulture (*Gypogeranus serpentarius*)	1
South American condor (*Sarcorhamphus gryphus*)	1
California condor (*Gymnogyps californianus*)	3
Griffon vulture (*Gyps fulvus*)	2
Cinereous vulture (*Vultur monachus*)	2
Egyptian vulture (*Neophron percnopterus*)	1
Turkey vulture (*Cathartes aura*)	4
Black vulture (*Catharista urubu*)	2
King vulture (*Gypagus papa*)	2
Snow pigeon (*Columba leuconota*)	2
Red-billed pigeon (*Columba flavirostris*)	4
White-crowned pigeon (*Columba leucocephala*)	2
Band-tailed pigeon (*Columba fasciata*)	4
Mourning dove (*Zenaidura macroura*)	7
Peaceful dove (*Geopelia tranquilla*)	2
Zebra dove (*Geopelia striata*)	22
Collared turtle-dove (*Turtur risorius*)	16
Cape masked dove (*Œna capensis*)	4

Australian crested pigeon (*Ocyphaps lophotes*)	16
Wonga-wonga pigeon (*Leucosarcia picata*)	12
Blue-headed quail-dove (*Starnœnas cyanocephala*)	4
Red-billed curassow (*Crax carunculata*)	1
Mexican curassow (*Crax globicera*)	2
Daubenton's curassow (*Crax daubentoni*)	2
Wild turkey (*Meleagris gallopavo silvestris*)	17
Peafowl (*Pavo cristata*)	69
Peacock pheasant (*Polyplectron chinquis*)	1
Silver pheasant (*Euplocamus nycthemerus*)	1
Bobwhite (*Colinus virginianus*)	1
Curaçao crested quail (*Eupsychortyx cristatus*)	3
Scaled quail (*Callipepla squamata*)	1
Valley quail (*Lophortyx californica vallicola*)	2
Gambel's quail (*Lophortyx gambeli*)	1
Massena quail (*Cyrtonyx montezumæ*)	1
American coot (*Fulica americana*)	5
Great bustard (*Otis tarda*)	1
Common cariama (*Cariama cristata*)	1
Demoiselle crane (*Anthropoides virgo*)	7
Crowned crane (*Balearica pavonina*)	2
Whooping crane (*Grus americana*)	1
Sand-hill crane (*Grus mexicana*)	4
Australian crane (*Grus australasiana*)	1
European crane (*Grus cinerea*)	1
Lilford's crane (*Grus lilfordi*)	4
Indian white crane (*Grus leucogeranus*)	2
White-necked crane (*Grus leucauchen*)	1
Ruff (*Machetes pugnax*)	1
Black-crowned night heron (*Nycticorax nycticorax nævius*)	12
Snowy egret (*Egretta candidissima*)	3
Great blue heron (*Ardea herodias*)	1
Great black-crowned heron (*Ardea cocoi*)	1
Boatbill (*Cancroma cochlearia*)	2
Black stork (*Ciconia nigra*)	1
Marabou stork (*Leptoptilus dubius*)	1
Wood ibis (*Mycteria americana*)	1
Sacred ibis (*Ibis æthiopica*)	3
White ibis (*Guara alba*)	12
Roseate spoonbill (*Ajaja ajaja*)	2
European flamingo (*Phœnicopterus roseus*)	2
Black-necked screamer (*Chauna chavaria*)	3
Horned screamer (*Palamedea cornuta*)	1
Whistling swan (*Olor columbianus*)	4
Trumpeter swan (*Olor buccinator*)	2
Mute swan (*Cygnus gibbus*)	5
Black swan (*Chenopis atrata*)	3
Spur-winged goose (*Plectropterus gambensis*)	1
White muscovy duck (*Cairina moschata*)	1
Wood duck (*Aix sponsa*)	6
Mandarin duck (*Dendronessa galericulata*)	27
Cape Barren goose (*Cereopsis novæ hollandiæ*)	2
Lesser snow goose (*Chen hyperboreus*)	3
Greater snow goose (*Chen hyperboreus nivalis*)	1
Blue goose (*Chen cærulescens*)	2
Ross's goose (*Chen rossi*)	1
American white-fronted goose (*Anser albifrons gambeli*)	5
Barred-head goose (*Anser indicus*)	2
Chinese goose (*Anser cygnoides*)	2
Canada goose (*Branta canadensis*)	17
Hutchins's goose (*Branta canadensis hutchinsii*)	6
Cackling goose (*Branta canadensis minima*)	2
Bernicle goose (*Branta leucopsis*)	2
Upland goose (*Chloëphaga magellanica*)	1
White-faced tree duck (*Dendrocygna viduata*)	3
Fulvous tree duck (*Dendrocygna bicolor*)	2
Wandering tree duck (*Dendrocygna arcuata*)	4
Ruddy sheldrake (*Casarca ferruginea*)	1
Mallard (*Anas platyrhynchos*)	5
East Indian black duck (*Anas sp.*)	4
Black duck (*Anas rubripes*)	1
European widgeon (*Mareca penelope*)	1
Pintail (*Dafila acuta*)	2
Blue-winged teal (*Querquedula discors*)	11
Rosy-billed pochard (*Metopiana peposaca*)	1
Red-headed duck (*Marila americana*)	1
American white pelican (*Pelecanus erythrorhynchos*)	9
European white pelican (*Pelecanus onocrotalus*)	2
Roseate pelican (*Pelecanus roseus*)	2
Brown pelican (*Pelecanus occidentalis*)	5
Australian pelican (*Pelecanus conspicillatus*)	2
Florida cormorant (*Phalacrocorax auritus floridanus*)	17
Water turkey (*Anhinga anhinga*)	3
Great black-backed gull (*Larus marinus*)	1
American herring gull (*Larus argentatus smithsonianus*)	2
Laughing gull (*Larus atricilla*)	2
South African ostrich (*Struthio australis*)	4
Somali ostrich (*Struthio molybdophanes*)	1
Common cassowary (*Casuarius galeatus*)	1
Common rhea (*Rhea americana*)	2
Emu (*Dromæus novæ hollandiæ*)	2

REPTILES.

Alligator (*Alligator mississippiensis*)	27
Painted box tortoise (*Cistudo ornata*)	2
Duncan Island tortoise (*Testudo ephippium*)	2
Albemarle Island tortoise (*Testudo vicina*)	1
Gila monster (*Heloderma suspectum*)	3
Regal python (*Python reticulatus*)	3
Common boa (*Boa constrictor*)	4
Anaconda (*Eunectes murinus*)	1
Black snake (*Zamenis constrictor*)	3
Coach-whip snake (*Zamenis flagellum*)	1
Water snake (*Natrix sipedon*)	5
Common garter snake (*Eutænia sirtalis*)	1
Texas water snake (*Eutænia proxima*)	1
King snake (*Ophibolus getulus*)	3
Copperhead (*Ancistrodon contortrix*)	1

STATEMENT OF THE COLLECTION.

ACCESSIONS DURING THE YEAR.

Presented	66
Purchased	105
Born and hatched in the National Zoological Park	101
Received in exchange	187
Received from Yellowstone National Park	2
Captured in National Zoological Park	1
Deposited in National Zoological Park	12
Total	474

SUMMARY.

Animals on hand July 1, 1915	1,397
Accesssions during the year	474
	1,871
Deduct loss (by exchange, death, return of animals, etc.)	488
On hand June 30, 1916	1,383

Class.	Species.	Individuals.
Mammals	155	574
Birds	189	751
Reptiles	16	58
Total	360	1,383

VISITORS.

The number of visitors to the park during the year, as determined by count and estimate, was 1,157,110, a daily average of 3,162. This was the largest year's attendance in the history of the park. The greatest number in any one month was 248,080, in April, 1916, an average per day of 8,269. The attendance by months was as follows:

1915.—July, 71,900; August, 79,100; September, 100,200; October, 121,000; November, 90,300; December, 34,050.

1916.—January, 55,200; February, 58,380; March, 95,800; April, 248,080; May, 128,200; June, 74,300.

One hundred and sixty-one schools, classes, etc., visited the park, with a total of 8,679 individuals.

IMPROVEMENTS.

The hospital and laboratory building which was mentioned in last year's report has been nearly completed, lacking only the interior fittings and the necessary outside yards. It is a pleasing structure, built, after the designs of the municipal architect, of blue gneiss of this neighborhood, warmly colored by infiltration of iron oxide. A retaining wall was built and some grading done to provide sufficient

area near the building for quarantine quarters for such animals as do not require artificial heat. Many of the chestnut trees surrounding the building became blasted by the "chestnut blight" and had to be cut down. A roadway of tar-bound macadam was constructed about the building connecting with the nearest main driveway. Connection with the nearest sewer (in Klingle Road) has been effected. Preparation should now be made to put the laboratory into effective operation. A modest supply of the necessary apparatus should be furnished in order that suitable facilities may be available for post mortem examination by the Government bureaus cooperating with the Zoological Park.

Attention has previously been called to the fact that the topography of the park is so irregular that it is difficult to find building sites with attached yards in convenient situations without extensive grading. A case in point occurs at the site of the barn which has been used for bison and other hoofed animals. The building here, made of logs with bark on, has become unsightly by decay and requires extensive repairs. It is situated on a hill of small elevation, but the slopes of which are sufficiently steep to cause continual erosion when it is worn by the hoofs of the animals. It was therefore thought best to grade down this hill and fill up the adjoining gullies, much enlarging the area of the yards. In order to do this effectively, it was necessary to borrow earth from the prominent ridge that extends from the zebu house northwesterly to the camel yards. About 25,000 square feet will be added to the level ground previously available. Only a portion of this work will be defrayed from the current appropriation, the remainder from next year's appropriation. The work was let out by contract, very favorable terms being secured. The additional paddocks thus obtained will be used, in part, for the exhibition of the beautiful ruminants presented to the park by the Duke of Bedford.

New sheds were built in the property yard for temporarily housing these animals and others displaced during the alteration of their regular quarters.

A needed convenience was provided at the elephant's quarters by installing, at small cost, hydraulic lifts to raise the heavy doors which give access to the outside yards.

The inclosure for ducks near the flight cage was reconstructed to make it safe from raccoons, etc.

A concrete driveway was constructed in the rear of the bear yards to provide for convenient transfer of animals and care of the quarters.

A motor truck was purchased during the year to haul food supplies, for which a trip is made every day except Sunday to the market

and the fish wharf. A shelter house for the truck was built near the food house.

Preparations were begun near the close of the year for building an additional toilet room for women, to be located in the valley a little below the large flight cage.

ALTERATION OF WESTERN BOUNDARY.

It appears desirable to recapitulate for future reference the various stages through which this matter has passed.

The following appropriation was made by the act approved June 23, 1913:

Readjustment of boundaries: For acquiring, by condemnation, all the lots, pieces, or parcels of land, other than the one hereinafter excepted, that lie between the present western boundary of the National Zoological Park and Connecticut Avenue from Cathedral Avenue to Klingle Road, $107,200, or such portion thereof as may be necessary, said land when acquired, together with the included highways, to be added to and become a part of the National Zoological Park. The proceedings for the condemnation of said land shall be instituted by the Secretary of the Treasury under and in accordance with the terms and provisions of subchapter 1 of chapter 15 of the Code of Law for the District of Columbia.

As the act requires that the proceedings be instituted by the Secretary of the Treasury, the attention of that official was called to the matter in a letter from the Secretary of the Smithsonian Institution, dated June 28, 1913. A special survey and plat of the land required was necessary, but this plat was not forwarded to the Department of Justice until November 5, 1913. Other delays ensued; the title of the various owners of the land had to be investigated, and it was not until March 11, 1914, that the District court ordered a jury to be summoned. A hearing was set for April 10, 1914, and a final hearing of the case was heard by the jury on July 2 following. The verdict of the jury was not filed until December 11, 1914. The hearing of objections to the verdict much delayed a final conclusion, especially as the time of the court was almost wholly occupied by a contest in an important will case. It was not until June 28, 1915, over two years from the passage of the appropriation act, that the court confirmed the verdict as regards the awards for damages for the land to be taken. The benefits assessed against the neighboring property were set aside by this and by a subsequent decision of January 28, 1916. The decree of the court fixed the amount required for the purchase of the land at $194,438.08. The cost of the proceedings for condemnation was $2,203.35.

The great delay caused by these legal proceedings occasioned another complication. The appropriation made by the act of June 23, 1913, was not a continuing one, but lapsed at the end of one year.

Consequently after June 30, 1915, there was nothing available to defray the purchase of the land.

An item for an additional appropriation and for a reappropriation of the original sum appropriated by the act of June 23, 1913, was submitted to Congress, but was not favorably considered by the House of Representatives. It was introduced in the Senate as an amendment to the sundry civil bill, but was dropped by the conference committee.

A similar item was offered in the Senate as an amendment to the District of Columbia appropriation bill, was accepted in Committee of the Whole, but thrown out finally in consequence of an appeal for retrenchment.

It is greatly to be regretted that this appropriation failed, as it is exceedingly desirable that the anomalous and inconvenient situation of the park should be remedied as soon as possible. It now fronts on no principal thoroughfare and attains none of the dignity which an institution controlled by the Government should have.

IMPORTANT NEEDS.

Aviary building.—Attention has been called to the need for this building in almost every annual report since 1908. The following is an extract from that document:

> The temporary bird house is crowded during the winter far beyond its proper capacity, and it is impossible to care for the birds satisfactorily. When it was built, and also at the time that additions were made, the funds available for the purpose were so small that it was necessary to build in the cheapest manner possible, so that the house has already required considerable repair and will very soon have to be largely rebuilt. The park has a good collection of birds, including a number of rare, interesting, and valuable specimens, sufficient to fill at once a large aviary and make one of the most important and attractive features of the park.

In the report for 1909 will be found the following:

> The need for a structure of this character is evident to any intelligent visitor to the park. Only a part of the collection can now be exhibited to the public, because of lack of room. A number of outdoor shelters and cages should also be provided for the exhibition of hardy birds.

Again, in the report for 1912 will be found:

> In spite of all efforts the fine collection of birds in the park is very far from being adequately housed. The wooden building in which the larger number are kept is too small, too low, insanitary, and really unworthy of a national institution. It was built in the cheapest manner to meet an emergency, and, although considerable sums have been spent on it for repairs, it is far from satisfactory. It is desired to build a suitable aviary in the western part of the park and to group about this the cages for the eagles, vultures, condors, and owls, now scattered somewhat irregularly about the grounds. It is believed that a suitable structure can be built for about $80,000.

It was again urged in 1914 as follows:

Attention has been called for several years past to the importance of erecting a suitable house for the care and preservation of the birds of the collection, most of which are now housed in a low wooden temporary structure which is by no means suitable for the purpose and has to be constantly renewed by repairs. The matter has been repeatedly urged upon Congress and an appropriation of $80,000 asked for a new structure. This is by no means an extravagant sum, as the aviaries of most zoological collections cost considerably more than this.

Also, in 1915:

Progressive deterioration of the temporary bird house again made repairs necessary there. The wooden floor, which had already been rebuilt twice, was replaced with concrete, as was also a part of the wooden foundation. The cost of this work was $700. This building is an example of the ultimate costliness of cheap temporary construction.

* * * * * * *

An aviary building is still a most urgent need, and repeated efforts have been made to secure an appropriation for this purpose.

It has been with great difficulty that the collection of birds has been kept in a fairly presentable condition. The building in which they are housed is a very common frame structure that has been repaired several times. The birds are crowded and not exhibited to advantage. In view of the fact that fine aviaries have been built at New York, Philadelphia, Boston, and Chicago, it seems most unfortunate that the national collection should have to be housed in this manner. It has been most unfavorably criticised by visitors.

The urgent needs of the park will be by no means satisfied by the construction of an aviary only. There are other buildings urgently needed for the proper housing and exhibition of the animals and the comfort of the public. Among these are the following mentioned in the report of last year:

A building for elephants, hippopotami, and similar animals.—The park has at present several interesting animals belonging to this group, including two species of elephants, two fine hippopotami, four tapirs, and other specimens. Some of these animals are large and powerful, and it is difficult to keep them safely in the insecure quarters to which it has been necessary to assign them. It is also reasonably certain that other similar animals will be added to the collection within a short time. A house for this group should be substantially constructed and occupy a space of at least 170 by 88 feet, with cages on both sides, 80 feet deep on one side and 60 feet on the other.

A public comfort building and restaurant.—This should be a building about 80 feet by 60 feet, including porches and a rest room for ladies. It is urgently needed, as the park is a considerable dis-

tance from town and is annually visited by over 1,000,000 people, including many young children. The present restaurant is so only in name, it being a makeshift affair, open on all sides, established on a temporary platform and affording no shelter during the driving and violent rainstorms that are so common here in summer. It frequently occurs that large numbers of people are drenched with rain before they can traverse the considerable distance between the deep valley in which the park is situated and a place of shelter. Most zoological parks are provided with spacious and commodious quarters of this kind.

Gatehouses.—Suitable gatehouses should be erected at the principal entrances to the park, viz: Those near Connecticut Avenue, at Quarry Road (Harvard Street), and at Adams Mill Road. It is sometimes necessary to close the entrances promptly, as in the case of the escape of an animal or for arrest of some offender. Besides this, the present entrance gates are far from dignified or suitable for a Government institution. They are properly merely temporary, awaiting the time when the boundaries of the park are definitely fixed. Each gatehouse should have not only quarters for the watchman but also toilet facilities.

Boundary fence.—In connection with this the inclosing boundary fence of the park should be considered. The present fence is of the type known as the "Page woven-wire fence."

It is believed that it would be more economical and efficient to construct a practically permanent iron fence than to replace the present nearly worn-out structure by another of similar character. It is suggested that the matter be referred to several iron-fence builders with a request for designs and prices. While the first cost of such a fence would undoubtedly be much greater, it would many times outlast the present structure and could be absolutely depended on to stop animals and men. Certain animals and game birds could be allowed to run at large within the park were it entirely certain that the fence would prevent their escape. We already have at large peacocks, wild turkeys, and squirrels, and it would be easy to considerably increase this list. It should be remembered that on several rare occasions caged animals have become loose within the park, and it is by no means certain that such accidents will not again occur. A few years ago the superintendent of the park was sued for damages alleged to be due to the escape of a wolf. The park is well wooded and a sudden heavy gale may throw tree trunks across the paddock fences, breaking them down and thus leading to the escape of the animals. Should this occur during the darkness of a stormy night it would be practically impossible for the keepers and watchmen to confine the animals again until daylight.

These improvements were urged in the last year's report. There are others perhaps equally important which are needed to bring the establishment up to the modern standard of what a zoological park ought to be. Most of these have been mentioned from time to time in other reports or have been urged upon the appropriation committees of Congress. They are briefly as follows:

Administration building.—The present office of the park is in an old dwelling house situated rather remotely from the buildings for the animals and inconveniently for the prompt and constant supervision of the operations of the park, as is the general practice in the foreign zoological gardens. A modest office building should now be erected in a central location. This would greatly expedite the general work of the park and improve the discipline of the working force. It is estimated that a building 50 by 36 feet, to contain office rooms, a drafting room, and a room for specimens would be sufficient.

Stable and forage barn.—There should be a stable and garage where the work horses and automobiles of the park could be stored. These should be on the ground floor, a storage loft for forage above. The dimensions should be at least 100 by 40 feet.

Shop.—The present shop is not large enough to accommodate conveniently the carpenters employed at the park. The woodworking plant is now dangerously near the blacksmith shop and the central heating plant. A separate building 100 by 46 feet should be erected.

Ape house.—Special quarters should be provided for the large anthropoid apes. These are probably the most interesting animals that can be exhibited and require special treatment and care. The group comprises the gorilla, the orang, several species of chimpanzee and of gibbon. They are so nearly related to man that observation and study of them is of the highest importance. The park has now only a chimpanzee, and it has been necessary to provide special quarters for him. It would be quite proper to place in the same building some of the larger species of baboons, as they require nearly the same treatment. A house for these animals should have a main building 150 by 60 feet, cages on both sides, and a wing 90 by 60 feet also, with similar cages. Outside cages should be erected along the 150 feet of the main building 18 feet deep, along the sides and end of wing 16 feet deep.

Lion house.—The house now occupied by the cat tribe is quite too small for the purpose, and it has always been intended to increase its capacity both by replacing the wooden extension by a masonry structure and by building an addition 120 feet long across the north end of the present building. This, of course, would be fitted with cages both within and without.

Reptile house.—No properly appointed house for reptiles now exists here, and the few specimens we have are inconveniently and unsuitably exhibited in the lion house. There should be a house 120 by 50 feet, with properly fitted cases on both sides and having a wing 20 by 50 feet with table exhibits. This would enable the park to exhibit all the important snakes of the United States and the principal ones of the western hemisphere, as well as the cobras and others of tropical East India; also the extremely varied group of lizards, the different species of crocodiles, etc.

Tortoise house.—Almost at the inception of the park a group of giant tortoises from the Galapagos Islands was obtained from Hon. Walter Rothschild. These still remain and might well form the nucleus of a collection of the tortoises of the world. A house 80 by 45 feet, with cages on both sides and yards 16 feet deep, would accommodate such a collection.

House for zebras, wild asses, and others of the horse family.—The park has already an interesting exhibit of this family including the Mongolian wild horse and two species of zebra. This should be enlarged and suitable quarters provided in a house 120 by 44 feet. The stalls should be on one side only and yards 50 feet deep be arranged.

House for tropical antelopes.—The teeming African fauna should be represented much more fully. It would require a house at least 175 feet by 75 with stalls on both sides and with commodious yards arranged about it in an elliptical form ranging in depth from 40 feet to 80 feet. Some of the stalls should be fitted up for giraffes.

House for tropical deer and swine.—A few specimens are already found in the collection. An adequate exhibit would require a house 100 feet by 45 feet with cages on both sides, the yards 30 feet deep on one side and 50 feet on the other.

House for marsupials.—The group of pouched animals, such as kangaroos, wallabies, opossums, wombats, Tasmanian wolves, etc., should be exhibited apart from the other mammals. These animals are dying out, rapidly diminishing in number year by year. They should have a house 120 feet by 40 feet with cages on both sides, the yards being 60 feet deep on one side, 20 feet on the other.

Pheasantry.—Besides the general aviary building, which it is hoped may soon be erected, separate quarters should be provided for certain groups of birds. Among these are the pheasants, comparatively hardy birds of very showy plumage, offering great variety. An exhibit can be secured at a reasonable expense. A house for them should be a low structure 140 by 18 feet. Visitors should not be admitted to this house; the birds would be seen in the outside yards which should be about 25 feet deep. A small appropriation will be asked of the present Congress for the establishment of a pheasantry.

Ostrich house.—The ostriches and their near relatives the emus, the rheas, and the cassowaries are so large and important that they should have a house to themselves. This should be 120 feet by 35 feet, with cages on one side only and yards giving plenty of room for exercise from 30 to 100 feet deep.

Tropical waterfowl.—These birds require heat during the cold season and the house would be really their winter quarters. During the summer they would be in the large "flight cage" or in some other outdoor inclosure. A house 120 by 50 feet, with cages on one side and one end, would be required.

Tropical birds of prey.—These require similar treatment but could not, of course, be housed with the waterfowl. A house 80 by 45 feet with cages on both sides and outside cages 18 feet deep would be needed.

Aquarium.—An exhibit of fish and other aquatic creatures is necessary to a complete survey of the domain of zoology. Such an exhibit was for a few years shown at the park and was one of the most popular features of the collection. It was installed in a rude frame structure erected for temporary use as a carpenters' shop. The tanks and other apparatus were furnished by the United States Fish Commission, having been used at the Atlanta Exposition. The building became quite unsafe and in 1901 Congress was asked to appropriate $25,000 toward the construction of a permanent structure. As this was not granted it became necessary to abandon the exhibit until such time as Congress may enable it to be properly housed. A building about 130 by 50 feet would be sufficient for the present.

Insectary.—In several European gardens an exhibit under glass is made of social and other interesting insects, such as ants, bees, wasps, butterflies, moths, etc. These have proved very attractive and are inexpensive. A house 60 feet by 30 feet with wall cases and table cases would accommodate such an exhibit.

The foregoing list merely recapitulates the needs of a fairly complete establishment such as may be seen in the European capitals. It would be well if the municipal architect, to whom the park is required to go for plans and specifications for buildings, could be asked to prepare estimates of cost for all of the above improvements to present to Congress.

In order to accommodate the buildings a considerable amount of grading should be done. The park is already cramped for space for convenient parking of vehicles upon crowded days. Over 50 automobiles and sight-seeing cars are sometimes assembled here at once, and there is great difficulty in managing them. A request for an appropriation of $4,000 for grading banks and filling ravines which was asked of Congress last year will be renewed.

Automobile.—The office of the park very much needs to have a small automobile for use in attending to the public business. The distances within the park itself are so considerable that it is a great waste of time and energy to traverse them on foot, or by horse vehicle, and the use of an automobile would greatly increase efficiency in the business of the park. The purchase does not involve any increase of the appropriation for the park, but merely the insertion of a clause in the appropriation act authorizing the purchase of a motor-propelled vehicle.

Roads.—The ordinary thoroughfares in the park were, at the close of the fiscal year, in fair condition. Nothing has been done, however, toward the repairing of the injury done by the construction by the District of the main trunk sewer known as the Rock Creek Main Interceptor. Attempts were made to get an appropriation to repair this defacement of the natural beauty of the park, but as yet without avail. The remarks then made were as follows:

> By authority of Congress a large sewer has been constructed on the right bank of Rock Creek through the entire length of the park, part of it being laid in a deep open cut, and part of it in a tunnel. A very large amount of rock has been excavated by blasting and this has been piled along the bank of the stream, destroying the natural beauty of the park by large piles of fragments of stone. While the contractor was required to "restore the surface as nearly as possible to the condition in which he found it," yet the amount of disturbance is so great that it is practically impossible to do this. It is proposed to cover these stone heaps with earth and to plant upon them trees and shrubs which will modify the unsightly appearance. A narrow road can be formed upon the top of the open cut sewer which will be a convenience to the public entering the park from the southern end.

The general appropriation for the park has remained at $100,000 per annum for six years past. This has had to suffice for the repairs and construction of buildings, the care of grounds, and the maintenance of roads and walks. In the meantime the cost of supplies, materials of all kinds, and labor has steadily increased so that there has been no opportunity to make even the most necessary improvements. The appropriations should be markedly increased, since a well-equipped zoological park is something of which the nation may well be proud.

Respectfully submitted.

Frank Baker,
Superintendent.

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution,
Washington, D. C.

APPENDIX 5.

REPORT ON THE ASTROPHYSICAL OBSERVATORY.

SIR: I have the honor to present the following report on the operations of the Smithsonian Astrophysical Observatory for the year ending June 30, 1916.

EQUIPMENT.

The equipment of the observatory is as follows:

(*a*) At Washington there is an inclosure of about 16,000 square feet, containing five small frame buildings used for observing and computing purposes, three movable frame shelters covering several out-of-door pieces of apparatus, and also one small brick building containing a storage battery and electrical distribution apparatus.

(*b*) At Mount Wilson, Cal., upon a leased plat of ground 100 feet square, in horizontal projection, are located a one-story cement observing structure, designed especially for solar-constant measurements, and also a little frame cottage, 21 feet by 25 feet, for observer's quarters. Upon the observing shelter at Mount Wilson there is a tower 40 feet high above the 12-foot piers which had been prepared in the original construction of the building. This tower is equipped with a tower telescope for use when observing (with the spectrobolometer) the distribution of radiation over the sun's disk.

During the year apparatus for research has been purchased or constructed at the observatory shop. The value of these additions to the instrumental equipment is estimated at $1,500.

WORK OF THE YEAR.

1. AT WASHINGTON.

Some years ago the Institution lent the Harvard College Observatory a silver-disk pyrheliometer for use at Arequipa, Peru. By request of Prof. Pickering the observations which had accumulated since August, 1912, were reduced at the Astrophysical Observatory and published by the Smithsonian Institution during the past year.[1] Owing to the high altitude of Arequipa the variations of solar radiation observed at a fixed zenith distance of the sun (as, for instance,

[1] Arequipa Pyrheliometry, Smithsonian Misc. Coll., Vol. 65, No. 9, 1916.

that whose secant is 1.2) were found to be almost wholly governed by three things—the atmospheric humidity, the distance of the sun, and the variations of the sun's emission. Hence from measurements of the humidity by the psychrometer it was possible to compute from the observed radiation the probable intensity of the solar radiation outside the atmosphere for each day. These empirical solar-constant values from Arequipa observations confirm the variations of the sun observed at Mount Wilson by the complete spectrobolometric process. Indeed, it appears that if eight or ten well-separated stations at high altitudes should be equipped with the pyrheliometer and psychrometer their combined results might well be expected to determine closely enough the sun's variations. A most interesting feature of Arequipa observations is that there is nothing anomalous about the observations of 1912 to suggest that the volcanic eruption of Mount Katmai (of June 6, 1912), which produced a great deal of dust all over the northern hemisphere, produced any turbidity of the atmosphere whatever south of the Equator.

Results of Mount Wilson solar-constant observations have been furnished in advance of publication to Dr. Bauer of the Carnegie Institution for comparison with magnetic data. He finds a close correlation between certain fluctuations of the earth's magnetic field and the variations of solar radiation.

The tower-telescope observations of the distribution of radiation along the diameter of the sun's disk, made at Mount Wilson in 1913 and 1914, having been fully reduced, a preliminary publication of them has been made by the Smithsonian Institution.[1] These results show distinctly that the average distribution of solar radiation over the solar disk varies from year to year. Greater contrast of brightness between the center and limb of the sun prevailed in 1907 and 1914 than in 1913. The change is greater for short wave lengths than for longer ones. Changes also occur from day to day. Both of these kinds of changes are found correlated with changes of the solar constant of radiation, but in opposite senses. High values of the solar radiation attend periods of greater solar activity and are associated with increased contrast of brightness between the center and edge of the solar disk. For short-period fluctuations of solar radiation, however, low values of solar radiation are associated with increased contrast. It seems reasonable to suppose that the first kind of phenomena is caused by increased convection in the sun, bringing fresh radiating surfaces forward more rapidly, thus increasing the effective solar temperature. The second kind of phenomena may be caused by temporary increases of the turbidity of the outer solar envelopes, restricting the solar emission especially at the limb.

[1] On the distribution of radiation over the sun's disk and new evidence of the solar variability. Smithsonian Misc. Coll., Vol. 66, No. 5, May, 1916.

Mount Wilson observations of 1915, including both the solar-constant work and the tower work, have been almost all reduced.

Mr. Fowle has continued at intervals between other work the reduction of his numerous observations of the transmission of rays of great wave length through long columns of air of known humidity. Many sources of error have required to be considered and eliminated, and the reading and reduction of the curves of observation was extremely tedious. The results are at length reaching such a stage that it can be seen that they fall into excellent agreement and will be of high interest in connection with studies of the earth's temperature as dependent on its radiation outward toward space. In fact, the results of Mr. Fowle's work are expected to be ready for publication within a short time.

For some years we have endeavored to design and construct an instrument capable of measuring accurately the intensity of sky light by day and of radiation outward toward the whole sky by night. At last success seems to be reached in an instrument devised by Messrs. Abbot and Aldrich and constructed by Mr. Kramer. The instrument is called the pyranometer, from the Greek words πῦρ, fire, ἀνά, up, μέτρον, a measure; thus designating an instrument adapted to measure heat coming from or going to space above. The pyranometer is somewhat after the principle of the Ångström pyrheliometer, in that the intensity of radiation is measured by electrical compensating currents, whose strength is adjusted with reference to the indications of a delicate thermocouple. A full account of the instrument has been published by the Smithsonian Institution,[1] including the tests which have been made to determine its accuracy by comparisons in solar measurements with the pyrheliometer. Complete accord between the two instruments is found at all altitudes of the sun when due regard is paid to the fact that the pyranometer presents a horizontal surface. The pyranometer seems to be suitable for botanical investigations, for it is capable of measuring the radiation even in deep shade, as in forests and greenhouses, as well as in full sun. In short, it can measure radiation in all situations where plants are accustomed to grow, except under water.

The consideration of the pyranometer has led us to undertake the determination of the constant ordinarily called "sigma" of Stefan's formula of radiation, according to which the emission of a perfect radiator per square centimeter per second is equal to the fourth power of the absolute temperature multiplied by "sigma." In recent years a good deal of disagreement has arisen as to the value of "sigma." We require to use it for certain tests of the py-

[1] The pyranometer—an instrument for measuring sky radiation: Smithsonian Misc. Coll., Vol. 66, No. 7, May, 1916.

ranometer and have devised a new method which seems very free from error for making its determination. The apparatus has been constructed and is now set up practically ready for use.

2. AT MOUNT WILSON.

Messrs. Abbot and Aldrich continued observations at Mount Wilson of the solar constant of radiation from July 1 to October 22, 1915, and renewed the expedition early in June, 1916. Besides conducting solar-constant observations and determinations of the distribution of light over the sun's disk in seven different wave lengths on each favorable day, comparisons of the pyrheliometers used ordinarily on Mount Wilson were made in both 1915 and 1916 with standard water-flow pyrheliometer No. 3. The comparisons showed no change to have occurred in the sensitiveness of secondary pyrheliometers Nos. IV and VII, on whose readings rest the solar-constant determinations made at Mount Wilson since 1906.

A good deal of attention was also given to the installation and trial of a solar cooking apparatus comprising ovens heated by oil under gravity circulation maintained by heat collected by a concave cylindric mirror of about 100 square feet surface. The apparatus seems highly promising, but owing to a couple of defects was not in satisfactory operation until after the close of the period covered by this report.

3. PROPOSED SOLAR-CONSTANT EXPEDITION.

On recommendation of the writer an allotment was made from the Hodgkins fund of the Smithsonian Institution for the purpose of duplicating the solar-constant work of Mount Wilson at the most favorable station on the earth. The expedition is being prepared and will go forward, probably to South America, in the summer of 1917. It is intended to continue solar-constant determinations by the spectro-bolometric method on every favorable day in every month of the year for several years at both Mount Wilson and the station in South America, with a view to determining the dependence of the earth's climatic conditions on the sun's variations of radiation.

SUMMARY.

Observations of several kinds have been made, reduced, and published which support one another in confirming the variability of the sun, and some of which tend to indicate dual causes of it. An expedition is proposed to occupy the most favorable station in South America for several years, beginning in 1917, for the purpose of making, in connection with the Mount Wilson observations, a full

and accurate determination of the solar variation for comparison with climatic changes. Measurements of the transmission of long-wave rays through long columns of moist air are almost ready for publication and appear to be resulting very satisfactorily. A new instrument, called the pyranometer, for measuring skylight and nocturnal radiation has been tested and found accurate.

Respectfully submitted.

C. G. Abbot,
Director Astrophysical Observatory.

Dr. C. D. Walcott,
Secretary of the Smithsonian Institution.

APPENDIX 6.

REPORT ON THE LIBRARY.

SIR: I have the honor to submit the following report on the operations of the library of the Smithsonian Institution during the fiscal year ending June 30, 1916:

The number of packages of books received during the year was 31,017, as compared with 29,928 packages in the year preceding. Of these 29,619 were received by mail and 1,400 through the International Exchange Service. Correspondence in connection with these included 1,241 letters and 3,997 acknowledgments on the regular printed form. The total accessions of books, pamphlets, and parts of sets aggregated 11,755.

SMITHSONIAN MAIN LIBRARY.

Publications for the main Smithsonian library are forwarded each day, after entering, to the Smithsonian deposit in the Library of Congress. Those catalogued and accessioned during the fiscal year numbered in all 18,637, which may be further described as 3,101 volumes, 739 parts of volumes, 383 pamphlets, 13,155 periodicals, 211 charts and 1,038 parts of serials to complete sets; extending the numbers in the accession book from 521,617 to 525,255.

The cataloguing included 5,045 volumes, 200 charts, and the adding of 738 new titles and the making of 5,329 typewritten cards; 3,480 printed cards from the Library of Congress for publications deposited by the Institution were filed in the catalogue. In addition, 3,596 volumes were recatalogued on standard size cards, from the old catalogue for inclusion in the new catalogue.

Documents relating to public matters and statistics of foreign countries, presented to the Smithsonian Institution largely in return for its own publications, were forwarded to the Library of Congress without stamping or recording, continuing a policy of some years standing. The publications sent in this way numbered 4,642.

Dissertations were received from Utrecht, Toulouse, Lund, Upsala, Leiden, Leipzig, Giessen, Paris, Bern, Pennsylvania, and Johns Hopkins, and from the Technical Hochschules of Berlin and Stuttgart.

Mr. Herbert A. Gill, administrator of the estate of Dr. Theodore Nicholas Gill, has presented his brother's scientific library to the Smithsonian Institution with the understanding that it is to be credited to the estate and that such publications as relate to the work of the Museum shall be placed in that library.

The securing of exchanges in return for Smithsonian publications and missing parts to complete the sets have been continued, notwithstanding war conditions abroad, and the results have added new titles and completed sets and series. In response to the requests for missing parts in the Smithsonian deposit in the Library of Congress 50 sets were completed and 1,038 parts supplied. These numbers include the completing of 30 sets in the series of publications of learned institutions and scientific societies, and the supplying of 824 parts and the completing of 20 volumes of periodicals, and the supplying of 212 separate numbers.

SMITHSONIAN OFFICE LIBRARY.

The office library includes a collection of books relating to art, the employees library, and various works of reference, besides quite an extensive aeronautical library.

In the reference room the transactions of scientific societies, and in the reading room the current foreign and domestic periodicals, have been in constant use. In the latter there are now 189 titles on the shelves.

In addition to the use of the library by the scientific staff of the Institution, almost all of the bureaus of the Government have availed themselves of the privileges of consulting and using the publications in the libraries.

From the reference and reading rooms in the Institution 3,330 publications were circulated during the year. Of these 473 were bound volumes and 2,857 were single periodicals.

Additions have been made to the aeronautical collection by way of exchange and by purchase of a few of the important works recently published. An acquisition of special value was a number of reference works formerly in the library of Maj. Baden-Powell.

A scrap book of articles from the older magazines is of interest, as describing early inventions in the arts, brought together and arranged in chronological order.

Dr. Alexander Graham Bell has continued to add to his collection of works relating to aeronautics by contributing 33 books and 37 portfolios and periodicals. This working library, which Dr. Bell used constantly while carrying on his experiments in aeronautics, will be of great value to students in the future. In addition to Dr. Bell's gift a total of 58 volumes were added during the year.

NATIONAL MUSEUM LIBRARY.

The library of the National Museum has been handicapped, as has almost every library in the country, by the nonreceipt of many European publications on account of the war.

Accessions.—There are now in the Museum library 47,713 volumes, 79,241 pamphlets and unbound papers, and 124 manuscripts. During the year just closed the accessions numbered 1,895 volumes, 2,873 pamphlets, and 72 parts of volumes.

Cataloguing.—New material was entered as received and sent out to the shelves or to the sectional libraries, so that it would be available at once to those interested. The recataloguing from the larger cards to the standard size, and the identification of the publications has been continued.

The new publications catalogued numbered 914 books, 3,157 pamphlets, and the total number of cards made was 4,669. The periodicals and parts of publications catalogued numbered 9,674, and periodical cards were made for 25 new publications; 2,025 section cards were made for periodicals assigned to sectional libraries, and 460 new periodical cards were written for the Museum library record.

There were recatalogued 135 books, 275 pamphlets, necessitating the making of 415 cards.

Exchanges.—Notwithstanding the conditions abroad, the efforts to secure missing parts and new exchanges have been continued. In connection with this work 257 letters were written, with the result that many parts that were lacking were supplied and many new titles were secured.

Loans.—During the year the loans from the general library numbered 12,085 publications, which includes books assigned to the sectional libraries, 4,978; 3,228 books borrowed from the Library of Congress, which included those from the Smithsonian collection; 207 from the Department of Agriculture library; 100 from the United States Geological Survey; 50 from the Army Medical Museum library; and 11 from other places. From the Museum shelves there were borrowed 3,511 volumes, and 1,899 section cards were made.

Binding.—The binding of the publications that have come to the Museum in parts, or paper covers, in order that they may be properly cared for and saved from destruction, is still a serious matter, as many remain unbound. It was possible this year to bind more than last year, which has relieved the situation; but it will take several years, at the present rate, to catch up with the needs of the library in this direction.

There were 799 volumes prepared and sent to the Government binder. Of this number 625 were returned to the Museum before the close of the year.

Gifts.—The following persons have contributed to the collection in the building: Dr. William Healey Dall, Dr. Edgar A. Mearns, Dr. Charles Doolittle Walcott, Dr. Oliver Perry Hay, Dr. F. Alexander McDermott, Dr. F. P. Dewey, Dr. Walter Hough, Mr. William R. Maxon, Dr. A. C. Peale estate, and the estate of Dr. Theodore Nicholas Gill.

Dall Collection.—Dr. William Healey Dall has continued to contribute to his collection of books relating to mollusks which he presented some years ago for the sectional library of the division of mollusks. Since July 1, 1915, he has added 207 titles.

Gill collection.—All the books and pamphlets from the estate of Dr. Theodore Nicholas Gill are being classified and arranged so that they can be properly distributed. From the hasty examination made in looking over the collection as it was being transferred it appears that the Museum library will have a valuable addition to its series of works relating to natural history, especially in ichthyology.

Technological series.—In this branch of the library there have been catalogued 1,052 volumes and 2,125 pamphlets, making a total of 3,177. The cards typewritten and filed in connection with this work numbered 3,505, the periodicals entered 3,631.

The books and pamphlets withdrawn for consultation in connection with the work of the Museum from this part of the library numbered 537. This is in addition to those borrowed from the central library.

The filing of cards in the scientific depository set of printed cards from the Library of Congress has been continued. Two thousand and thirty-three author cards and 4,031 subjects cards were placed in the alphabetical series.

Sectional libraries.—The checking of publications assigned to the sectional libraries has been continued as the other work would allow, and while some progress has been made the work is not near completion.

The following is a complete list of the sectional libraries:

Administration.
Administrative assistant's office.
Anthropology.
Biology.
Birds.
Botany.
Comparative anatomy.
Editor's office.
Ethnology.
Fishes.
Geology.
Graphic arts.
History.
Insects.

Invertebrate paleontology.
Mammals.
Marine invertebrates.
Materia medica.
Mechanical technology.
Mesozoic fossils.
Mineral technology.
Minerals.
Mollusks.
Oriental archeology.
Paleobotany.
Parasites.
Photography.
Physical anthropology.
Prehistoric archeology.
Property clerk.
Reptiles and batrachians.
Superintendent's office.
Taxidermy.
Textiles.
Vertebrate paleontology.

LIBRARY OF BUREAU OF AMERICAL ETHNOLOGY.

The collection of works relating to ethnology is administered by the ethnologist-in-charge, and an account of its operations will be found in the report of that bureau.

ASTROPHYSICAL OBSERVATORY LIBRARY.

The collection of reference works relating to astrophysics is in constant use, and during the year there were added 61 volumes, 20 parts of volumes, and 18 pamphlets.

NATIONAL ZOOLOGICAL PARK LIBRARY.

This library contains publications relating to the work of the park and the care of the animals, reports of other zoological parks, and works on landscape gardening. The number of publications added was 21 volumes and 5 pamphlets.

SUMMARY OF ACCESSIONS.

The accessions during the year, with the exception of the library of the Bureau of American Ethnology, may be summarized as follows:

To the Smithsonian deposit in the Library of Congress, including parts to complete sets	5,472
To the Smithsonian office, Astrophysical Observatory, and National Zoological Park	1,443
To the United States National Museum	4,840
Total	11,755

Respectfully submitted.

PAUL BROCKETT,
Assistant Librarian.

DR. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

APPENDIX 7.

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

SIR: I have the honor to submit the following report on the operations of the United States Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1916:

Each year 17 volumes of the catalogue are published by the Central Bureau in London, one volume for each of the following named sciences: Mathematics, mechanics, physics, chemistry, astronomy, meteorology, mineralogy, geology, geography, palaeontology, general biology, botany, zoology, anatomy, anthropology, physiology, and bacteriology.

The publication was begun in 1901, and since then all of the first 11 annual issues have been published, together with 14 volumes of the twelfth issue, 10 volumes of the thirteenth issue, and 1 volume of the fourteenth, a total of 212 regular volumes, in addition to several special volumes of schedules, lists of journals, etc.

The 14 volumes of the twelfth issue published are mathematics, mechanics, physics, chemistry, astronomy, meteorology, mineralogy, geography, palaeontology, general biology, botany, zoology, anatomy, and anthropology.

The 10 volumes of the thirteenth issue published are mathematics, mechanics, physics, astronomy, meteorology, mineralogy, geography, palaeontology, general biology, and zoology.

The one volume of the fourteenth issue published is zoology.

During the year there were 24,160 classified references to American scientific literature prepared by this bureau as follows:

Literature of—	
1908	6
1909	2
1910	75
1911	369
1912	835
1913	3,948
1914	8,750
1915	10,175
Total	24,160

It was, of course, inevitable that an international cooperative enterprise such as the International Catalogue should be affected by the

war in Europe, but it is a matter of congratulation that the preparation and publication has been continued with comparatively little change. As was pointed out in the last report the finances of the catalogue had been seriously affected on account of the inability to collect the subscriptions from Germany, Austria, Hungary, Belgium, and Poland.

Before the beginning of the war the receipts and expenditures of the London Central Bureau approximately balanced and therefore as the delinquent remittances from the five subscribing countries above mentioned amounted to almost $6,000 a year it was necessary to obtain this sum in order to continue the publication.

The Royal Society of London very generously offered to make good this loss of income and made a grant of £1,100 to enable the thirteenth annual issue to be published. The Royal Society has subsequently granted additional sums aggregating £3,750 to enable the Central Bureau to continue the publication of the catalogue without interruption.

A request having been made for assistance from the United States the Secretary of the Smithsonian Institution became so interested in the subject that he was enabled to obtain a grant of $6,000 from the Carnegie Corporation of New York for the purpose of aiding American students by making it possible for the Central Bureau to publish the fourteenth annual issue of the catalogue.

The value and service to science of the work done by the catalogue is so universally recognized that any lapse in its regular publication would be a serious calamity.

The great need for a Catalogue of Scientific Literature was felt as far back as 1855 when Prof. Joseph Henry brought the subject to the attention of the British Association for the Advancement of Science. The idea resulted in the Royal Society's Catalogue of Scientific Papers which will, when completed, be a catalogue of periodical scientific literature from 1800 to 1900.

Though this catalogue is simply a list of titles by authors' names, including only periodical literature, it soon became evident that its production was too great a task for one society or even one nation to continue; therefore in 1893 a council of the Royal Society was held and a committee was appointed to consider the question. It was agreed that international cooperation should be obtained for the production of a complete subject and author catalogue of science beginning with 1901.

The value of such a catalogue as then proposed may be estimated when it is considered that some of the most eminent scientific men of the day were members of the committee. Among the members were Lord Kelvin, Lord Rayleigh, Sir Michael Foster, Sir Joseph Lister, and Dr. Ludwig Mond. At the first meeting Prof. Armstrong

was elected chairman and he has ever since been prominently identified with the affairs of the catalogue.

To obtain international cooperation the committee caused over 200 letters to be sent to institutions and societies throughout the world and in 1895 a special meeting was called to confer with Prof. Alexander Agassiz, who advised that an international conference be called in 1896.

In the report of the committee it was stated "that in no single case was any doubt expressed as to the extreme value of the work contemplated," and "that the matter had been taken up in a most cordial manner by the Smithsonian Institution, the secretary of which, in his reply, refers to the desirability of a catalogue of the kind suggested as being so obvious that the work commends itself at once."

Three international conferences were held in London (1896, 1898, and 1900), and as a result the publication of the catalogue was undertaken.

It may be noted that among the prominent delegates attending these conferences (not including those before mentioned as members of the Committee of the Royal Society) were Sir Norman Lockyer, Prof. H. Poincaré, Prof. Simon Newcomb, Dr. John S. Billings, Right Hon. Sir. John E. Gorst, and Prof. Van't Hoff. On the advice of these and other prominent men the catalogue was begun.

The value of the catalogue is shown by the following resolution adopted 10 years after the publication was begun by the representatives of the countries participating in the work:

> That in view of the success already achieved by the International Catalogue of Scientific Literature and the great importance of the objects promoted by it, it is imperative to continue the publication of the catalogue at least during the period 1911–15 and on recommendation of the International Council during the subsequent five years 1916–20. (The International Council of the catalogue has subsequently voted to extend the work during the period 1916–20.)

This convention was presided over by Sir Archibald Geikie, then president of the Royal Society, and had among its members representatives from all of the principal countries of the world.

These men were thoroughly familiar with the service of the catalogue to the scientific men in their respective countries and voted unanimously to continue the work on account of the value and success achieved by it.

Respectfully submitted.

Leonard C. Gunnell,
Assistant in Charge.

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

APPENDIX 8.

REPORT ON THE PUBLICATIONS.

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the year ending June 30, 1916:

The Institution proper published during the year 22 papers in the series of Miscellaneous Collections, 2 annual reports, pamphlet copies of 54 papers from the general appendices of these reports, and 8 special publications. The Bureau of American Ethnology published 2 annual reports, separates of 4 accompanying papers in these reports, and 2 bulletins. The United States National Museum issued 1 annual report, 2 volumes of the proceedings, and 52 separate papers forming parts of these and other volumes, and 4 bulletins.

The total number of copies of publications distributed by the Institution and its branches was 153,262, which includes 249 volumes and separate memoirs of Smithsonian Contributions to Knowledge, 32,397 volumes and separate pamphlets of Smithsonian Miscellaneous Collections, 25,718 volumes and separate pamphlets of Smithsonian Annual Reports, 73,798 volumes and separates of National Museum publications, 12,420 publications of the Bureau of American Ethnology, 7,696 special publications, 47 volumes of the Annals of Astrophysical Observatory, 83 reports of the Harriman Alaska Expedition, and 647 reports of the American Historical Association.

SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

QUARTO.

The title-page, table of contents, and cover for volume 27 were issued, and there was in press at the close of the year a memoir by Dr. J. S. Foote, of Creighton Medical College, on "The comparative histology of the femur," the result of extended original research.

SMITHSONIAN MISCELLANEOUS COLLECTIONS.

OCTAVO.

Of the Miscellaneous Collections, volume 62, 2 papers were published; of volume 63, 1 paper; of volume 64, 3 papers; of volume 65, 8 papers and title-page and table of contents; of volume 66, 8 papers; in all, 22 papers, as follows:

Volume 62.

No. 4. Reports on wind tunnel experiments in aerodynamics. By J. C. Hunsaker, E. Buckingham, H. E. Rossell, D. W. Douglas, C. L. Brand, and E. B. Wilson. Hodgkins Fund. January 15, 1916. 92 pp., 5 pls. (Publ. 2368.)

No. 5. Dynamical stability of aeroplanes. By Jerome C. Hunsaker, assisted by T. H. Huff, D. W. Douglas, H. K. Chow, and V. E. Clark. Hodgkins Fund. June 30, 1916. 78 pp., 3 pls. (Publ. 2414.)

Volume 63.

No. 6. Smithsonian Physical Tables. Reprint of sixth revised edition. By F. E. Fowle. February 18, 1916. xxxvi+355 pp. (Publ. 2269.)

Volume 64.

No. 3. Cambrian Geology and Paleontology. III, No. 3. Cambrian trilobites. By Charles D. Walcott. January 14, 1916. Pp. 157–258, pls. 24–38. (Publ. 2370.)

No. 4. Cambrian Geology and Paleontology. III, No. 4. Relations between the Cambrian and pre-Cambrian formations in the vicinity of Helena, Montana. By Charles D. Walcott. June 24, 1916. Pp. 259–301, pls. 39–44. (Publ. 2416.)

No. 5. Cambrian Geology and Paleontology. III, No. 5. Cambrian trilobites. By Charles D. Walcott. In press.

Volume 65.

No. 3. A study of the radiation of the atmosphere. Based upon observations of the nocturnal radiation during expeditions to Algeria and to California. By Anders Ångström. Hodgkins Fund. August 27, 1915. 159 pp. (Publ. 2354.)

No. 6. Explorations and field work of the Smithsonian Institution in 1914. July 1, 1915. 95 pp., 1 pl. (Publ. 2363.)

No. 9. Arequipa pyrheliometry. By C. G. Abbot. Hodgkins Fund. March 1, 1916. 24 pp. (Publ. 2367.)

No. 10. A phylogenetic study of the recent crinoids, with special reference to the question of specialization through the partial or complete suppression of structural characters. By Austin H. Clark. August 19, 1915. 67 pp. (Publ. 2369.)

No. 11. A magneton theory of the structure of the atom. By A. L. Parson. November 29, 1915. 80 pp., 2 pls. (Publ. 2371.)

No. 12. The jaw of the Piltdown Man. By Gerrit S. Miller, jr. November 24, 1915. 31 pp., 5 pls. (Publ. 2376.)

No. 13. Descriptions of seven new subspecies and one new species of African birds (Plantain-Eater, Courser, and Rail). By Edgar A. Mearns. November 26, 1915. 9 pp. (Publ. 2378.)

No. 14. The sense organs on the mouth parts of the honey bee. By N. E. McIndoo. January 12, 1916. 55 pp. (Publ. 2381.)

Title-page and table of contents. June 17, 1916. v pp. (Publ. 2419.)

Volume 66.

No. 1. Descriptions of a new genus and eight new species and subspecies of African mammals. By N. Hollister. February 10, 1916. 8 pp. (Publ. 2416.)

No. 2. A list of the birds observed in Alaska and Northeastern Siberia during the summer of 1914. By F. Seymour Hersey. March 31, 1916. 33 pp. (Publ. 2408.)

No. 3. Explorations and field work of the Smithsonian Institution in 1915. May 27, 1916. 119 pp. (Publ. 2407.)

No. 4. The Ordaz and Dortal expeditions in search of El Dorado, as described on sixteenth century maps. By Rudolf Schuller. April 27, 1916. 15 pp., 2 maps. (Publ. 2411.)

No. 5. On the distribution of radiation over the sun's disk and new evidences of the solar variability. By C. G. Abbot, F. E. Fowle, and L. B. Aldrich. Hodgkins Fund. May 23, 1916. 24 pp., 1 pl. (Publ. 2412.)

No. 6. Phonetic transcription of Indian languages. In press.

No. 7. The Pyranometer—an instrument for measuring sky radiation. By C. G. Abbot and L. B. Aldrich. Hodgkins Fund. May 23, 1916. 9 pp. (Publ. 2417.)

No. 8. Three new African shrews of the genus Crocidura. By N. Hollister. May 23, 1916. 3 pp. (Publ. 2418.)

SMITHSONIAN ANNUAL REPORTS.

Report for 1914.

The completed volume of the Annual Report of the Board of Regents for 1914 was received from the Public Printer in August, 1915.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1914. xi+729 pp., 155 pls. (Publ. 2321.)

The general appendix contained the following papers, small editions of which were printed in pamphlet form:

The radiation of the sun. By C. G. Abbot. 16 pp., 4 pls. (Publ. 2322.)

Modern theories of the sun. By Jean Bosler. 8 pp., 2 pls. (Publ. 2323.)

The form and constitution of the earth. By Louis B. Stewart. 14 pp. (Publ. 2324.)

Some remarks on logarithms apropos to their tercentenary. By M. d'Ocagne. 7 pp., 2 pls. (Publ. 2325.)

Modern views on the constitution of the atom. By A. S. Eve. 9 pp. (Publ. 2326.)

Gyrostats and gyrostatic action. By Andrew Gray. 16 pp., 10 pls. (Publ. 2327.)

Stability of aeroplanes. By Orville Wright. 8 pp. (Publ. 2328.)

The first man-carrying aeroplane capable of sustained free flight—Langley's success as a pioneer in aviation. By A. F. Zahm. 6 pp., 8 pls. (Publ. 2329.)

Some aspects of industrial chemistry. By L. H. Baekeland. 25 pp. (Publ. 2330.)

Explosives. By Edward P. O'Hern. 27 pp., 7 pls. (Publ. 2331.)

Climates of geologic time. By Charles Schuchert. 35 pp. (Publ. 2332.)

Pleochroic haloes. By J. Joly. 15 pp., 3 pls. (Publ. 2333.)

The geology of the bottom of the seas. By L. de Launay. 24 pp. (Publ. 2334.)

Recent oceanographic researches. By Ch. Gravier. 10 pp. (Publ. 2335.)

The Klondike and Yukon goldfield in 1913. By H. M. Cadell. 20 pp., 6 pls. (Publ. 2336.)

The history of the discovery of sexuality in plants. By Duncan S. Johnson. 24 pp. (Publ. 2337.)

Problems and progress in plant pathology. By L. R. Jones. 13 pp. (Publ. 2338.)

Plant autographs and their revelations. By Jagadis Chunder Bose. 23 pp. (Publ. 2339.)

The National Zoological Park and its inhabitants. By Frank Baker. 34 pp., 41 pls. (Publ. 2340.)

On the habits and behavior of the herring gull. By R. M. Strong. 31 pp., 10 pls. (Publ. 2341.)

Notes on some effects of extreme drought in Waterberg, South Africa. By Eugène N. Marais. 12 pp. (Publ. 2342.)

Homœotic regeneration of the antennae in a Phasmid or walking-stick. By H. O. Schmit-Jensen. 14 pp., 2 pls. (Publ. 2343.)

Latent life: Its nature and its relations to certain theories of contemporary biology. By Paul Becquerel. 15 pp. (Publ. 2344.)

The early inhabitants of western Asia. By Felix v. Luschan. 25 pp., 12 pls. (Publ. 2345.)

Excavations at Abydos. By Edouard Naville. 7 pp., 3 pls. (Publ. 2346.)

An examination of Chinese bronzes. By John C. Ferguson. 6 pp., 14 pls. (Publ. 2347.)

The rôle of depopulation, deforestation, and malaria in the decadence of certain nations. By Felix Regnault. 5 pp. (Publ. 2348.)

The story of the chin. By Louis Robinson. 11 pp., 12 pls. (Publ. 2349.)

Recent developments in the art of illumination. By Preston S. Millar. 18 pp., 2 pls. (Publ. 2350.)

The loom and spindle: Past, present, and future. By Luther Hooper. 49 pp., 11 pls. (Publ. 2351.)

The demonstration play school of 1913. By Clark W. Hetherington. 29 pp. (Publ. 2352.)

Sketch of the life of Eduard Suess (1831–1914). By Pierre Termier. 10 pp. (Publ. 2353.)

Report for 1915.

The report of the executive committee and proceedings of the Board of Regents of the Institution, and the report of the Secretary, both forming part of the Annual Report of the Board of Regents to Congress, were issued in pamphlet form in December, 1915:

Report of the executive committee and proceedings of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1915. 21 pp. (Publ. 2380.)

Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1915. 110 pp. (Publ. 2379.)

Small editions of the following papers, forming the general appendix of the report for 1915, were issued in May, 1916, and the complete volume was received from the printer in June:

Review of astronomy for the year 1913, by P. Puiseux. 9 pp. (Publ. 2383.)

The utilization of solar energy, by A. S. E. Ackermann. 26 pp., 6 pls. (Publ. 2384.)

The constitution of matter and the evolution of the elements, by Ernest Rutherford. 36 pp., 5 pls. (Publ. 2385.)

Submarine signalling, by R. F. Blake. 11 pp. (Publ. 2386.)
The earthquake in the Marsica, Central Italy, by Ernesto Mancini. 4 pp., 1 pl. (Publ. 2387.)
Atlantis, by Pierre Termier. 16 pp. (Publ. 2388.)
Evidences of primitive life, by Charles D. Walcott. 21 pp., 18 pls. (Publ. 2389.)
The place of forestry among natural sciences, by Henry S. Graves. 13 pp. (Publ. 2390.)
Lignum Nephriticum, by W. E. Safford. 28 pp., 7 pls. (Publ. 2391.)
Impressions of the voices of tropical birds, by Louis Agassiz Fuertes. 25 pp., 16 pls. (Publ. 2392.)
The Eskimo Curlew and its disappearance, by Myron H. Swenk. 16 pp., 1 pl. (Publ. 2393.)
Construction of insect nests, by Y. Sjöstedt. 7 pp., 3 pls. (Publ. 2394.)
Olden time knowledge of Hippocampus, by C. R. Eastman. 9 pp., 4 pls. (Publ. 2395.)
Heredity, by William Bateson. 38 pp. (Publ. 2396.)
Some aspects of progress in modern zoology, by Edmund B. Wilson. 14 pp. (Publ. 2397.)
Linguistic areas in Europe: Their boundaries and political significance, by Leon Dominian. 35 pp., 5 maps. (Publ. 2398.)
Excavations at Tell el-Amarna, Egypt, in 1913–14, by Ludwig Borchardt. 13 pp., 13 pls. (Publ. 2399.)
Vaccines, by L. Roger. 8 pp. (Publ. 2400.)
Progress in reclamation of arid lands in the Western United States, by John B. Beadle. 22 pp., 13 pls. (Publ. 2401.)
Some recent developments in telephony and telegraphy, by Frank B. Jewett. 21 pp. (Publ. 2402.)
Sir David Gill, by A. S. Eddington. 12 pp. (Publ. 2403.)
Walter Holbrook Gaskell, by J. N. Langley. 10 pp. (Publ. 2404.)

Special publications.

The following special publications were issued in octavo form:

Publications of the Smithsonian Institution issued between January 1 and June 30, 1915. Published July 20, 1915. 2 pp. (Publ. 2372.)
Publications of the Smithsonian Institution issued between January 1 and September 30, 1915. October 25, 1915. 2 pp. (Publ. 2377.)
Publications of the Smithsonian Institution issued between January 1 and December 31, 1915. January 27, 1916. 3 pp. (Publ. 2405.)
Publications of the Smithsonian Institution issued between January 1 and March 31, 1916. April 20, 1916. 1 p. (Publ. 2413.)
Classified list of Smithsonian publications available for distribution, October 15, 1915. November 4, 1915. iv+32 pp. (Publ. 2375.)
Opinions rendered by the International Commission on Zoological Nomenclature. Opinion 67. April 27, 1916. Pp. 177–182. (Publ. 2409.)
Rules and regulations for the conduct of the work of the National Advisory Committee for Aeronautics. July 16, 1915. 5 pp.
Sources of nitrogen compounds in the United States. By Chester G. Gilbert. June 30, 1916. 12 pp. (Publ. 2421.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM.

The publications of the National Museum are: (*a*) The annual report to Congress; (*b*) the Proceedings of the United States Na-

tional Museum; and (c) the Bulletin of the United States National Museum, which includes the Contributions from the United States National Herbarium. The editorship of these publications is vested in Dr. Marcus Benjamin.

During the year the Museum published an annual report, 2 volumes of the Proceedings and 52 separate papers forming parts of these and other volumes, and 4 bulletins.

The issues of the Proceedings were as follows: Volume 48; volume 49, papers 2092, 2094 to 2130, and the complete volume; volume 50, papers 2131 to 2138. The Annual Report of the United States National Museum for 1915 was also published.

The bulletins were as follows:

Bulletin 50, The Birds of North and Middle America, part 7, by Robert Ridgway.

Bulletin 91, Report on the Turton collection of South African marine mollusks, with additional notes on other South African shells contained in the United States National Museum, by Paul Bartsch.

Bulletin 92, Bibliographic index of American Ordovician and Silurian fossils (two volumes), by Ray S. Bassler.

Bulletin 94, Handbook and descriptive catalogue of the meteorite collections in the United States National Museum, by George P. Merrill.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

The publications of the bureau are discussed in appendix 2 of the Secretary's report. The editorial work of the bureau has continued in charge of Mr. J. G. Gurley, editor.

During the year, 2 annual reports and 2 bulletins were issued, as follows:

29th Annual Report of the Bureau of American Ethnology (containing an accompanying paper, "The Ethnogeography of the Tewa Indians," by John Peabody Harrington).

30th Annual Report of the Bureau of American Ethnology (containing two accompanying papers, "Ethnobotany of the Zuni Indians," by Matilda Coxe Stevenson, and "An Inquiry into the animism and folklore of the Guiana Indians," by Walter E. Roth), and a "List of publications of the Bureau of American Ethnology."

Bulletin 57. An Introduction to the Study of the Maya Hieroglyphs, by Sylvanus Griswold Morley.

Bulletin 62. Physical anthropology of the Lenape or Delawares, and of the Eastern Indians in general, by Aleš Hrdlička. In press.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION.

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated to Congress under the provisions of the act of incorporation of the association.

The annual report for 1913 (2 volumes) was published during the year, and the first volume of the 1914 report was in press at the close of the fiscal year.

REPORT OF THE NATIONAL SOCIETY OF THE DAUGHTERS OF THE AMERICAN REVOLUTION.

The manuscript of the Eighteenth Annual Report of the National Society of the Daughters of the American Revolution for the year ending October 11, 1915, was communicated to Congress on March 28, 1916.

THE SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication. This committee passes on all manuscripts offered for publication by the Institution or its branches, and considers forms of routine, blanks, and various other matters pertaining to printing and publication. Eighteen meetings were held during the year and 96 manuscripts were acted upon.

Respectfully submitted.

A. Howard Clark, *Editor.*

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1916.

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution, and a statement of the appropriations by Congress for the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, and the International Catalogue of Scientific Literature for the year ending June 30, 1916, together with balances of previous appropriations:

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1916.

The permanent fund of the Institution and the sources from which it has been derived are as follows:

DEPOSITED IN THE TREASURY OF THE UNITED STATES.

Bequest of Smithson, 1846		$515, 169. 00
Residuary legacy of Smithson, 1867		26, 210. 63
Deposit from savings of income, 1867		108, 620. 37
Bequest of James Hamilton, 1875	$1, 000. 00	
Accumulated interest on Hamilton fund, 1895	1, 000. 00	
		2, 000. 00
Bequest of Simeon Habel, 1880		500. 00
Deposits from proceeds of sale of bonds, 1881		51, 500. 00
Gift of Thomas G. Hodgkins, 1891		200, 000. 00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8, 000. 00
Deposit from savings of income, 1903		25, 000. 00
Residuary legacy of Thomas G. Hodgkins, 1907		7, 918. 69
Deposit from savings of income, 1913		636. 94
Part of bequest of William Jones Rhees, 1913		251. 95
Deposit of proceeds from sale of real estate (gift of Robert Stanton Avery), 1913		9, 692. 42
Bequest of Addison T. Reid, 1914		4, 795. 91
Deposit of savings from income of Avery bequest, 1914		204. 09
Balance of bequest of William Jones Rhees, 1915		248. 05
Deposit of savings from income of Rhees bequest, 1915		28. 39
Deposit of savings from income of Avery fund, 1915		1, 862. 60
Deposit of savings from income of Reid fund, 1915		426. 04
Deposit of first payment of Lucy T. and George W. Poore fund, 1915		24, 534. 92

Deposit of part of principal of Addison T. Reid fund, 1916	$4,698.59
Deposit of principal of George H. Sanford fund, 1916	1,020.00
Deposit of savings from income, 1916	2,681.41
Total amount of fund in United States Treasury	996,000.00

OTHER RESOURCES.

Registered and guaranteed 4 per cent bonds of the West Shore Railroad Co., part of legacy of Thomas G. Hodgkins (par value)	42,000.00
Coupon 5 per cent bonds of the Brooklyn Rapid Transit Co., due July 1, 1918 (cost)	5,040.63
Coupon 6 per cent bonds of the Argentine Nation, due Dec. 15, 1917 (cost)	5,093.75
	1,048,134.38

Also three small pieces of real estate located in the District of Columbia and bequeathed by the late Robert Stanton Avery, of Washington, D. C.

That part of the fund deposited in the Treasury of the United States, now amounting to $996,000, bears interest at 6 per cent per annum, under the provisions of the act of Congress of August 10, 1846, organizing the Institution, and the act approved March 12, 1894.

The real estate bequeathed to the Institution by the late Robert Stanton Avery is exempt from taxation and yields only a nominal revenue from rentals.

Statement of receipts and disbursements from July 1, 1915, to June 30, 1916.

RECEIPTS.

Cash on deposit and in safe July 1, 1915		$42,165.86
Interest on fund deposited in United States Treasury due July 1, 1915, and Jan. 1, 1916	$59,071.23	
Interest on West Shore Railroad bonds, due July 1, 1915, and Jan. 1, 1916	1,680.00	
Repayments, rentals, publications, etc	9,265.45	
Contributions from various sources for specific purposes	22,954.99	
Frances Lea Chamberlain fund	10,000.00	
Addison T. Reid fund	4,698.59	
		107,670.26
		149,836.12

DISBURSEMENTS.

Buildings, care and repairs		5,718.46
Furniture and fixtures		1,451.61
General expenses:		
Salaries	18,783.21	
Meetings	163.25	
Stationery	830.39	
Postage, telegraph, and telephone	509.12	
Freight	86.82	
Incidentals, fuel, and lights	1,165.92	
Garage	1,950.16	
		23,578.87

Library		$2,545.91
Publications and their distribution:		
Miscellaneous collections	$4,218.26	
Contributions to knowledge	139.75	
Reports	324.58	
Special publications	209.82	
Publication supplies	221.05	
Salaries	6,862.90	
		11,976.36
Explorations, researches, and collections		5,441.85
Hodgkins specific fund, researches, and publications		3,068.57
International exchanges		4,043.31
Gallery of Art		21.88
Langley Aerodynamical Laboratory		70.95
Deposited to credit of permanent fund		8,400.00
Consolidated fund, purchase of bonds		10,134.38
Advances for field expenses, etc		28,672.95
Balance June 30, 1916:		
Deposited with the Treasurer of the United States	44,511.02	
Cash on hand	200.00	
		44,711.02
		149,896.12

Your executive committee again employed the Capital Audit Co. of this city to audit the receipts and expenditures of the Smithsonian Institution during the period covered by this report. An itemized report has been submitted, but the following certificate of examination supports the foregoing statement and is hereby approved:

AUDITOR'S STATEMENT.

CAPITAL AUDIT CO., METROPOLITAN BANK BUILDING,
Washington, D. C., August 14, 1916.

Executive Committee, Board of Regents, Smithsonian Institution.

SIRS: We have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ended June 30, 1916, and certify the following to be a correct statement:

Total receipts	[1] $107,662.46
Total disbursements	[1] 105,117.30
Excess of receipts over disbursements	2,545.16
Amount from July 1, 1915	42,165.86
Balance on hand June 30, 1916	44,711.02
Balance as shown by Treasury statement as of June 30, 1916	47,831.11
Less outstanding checks	3,320.09
Balance	44,511.02
Cash on hand	200.00
Balance June 30, 1916	44,711.02

[1] Does not include $7.80 Eastman Kodak Co. voucher No. 5638, entry and counter entry.

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the secretary, or in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them.

CAPITAL AUDIT CO.,
By WILLIAM L. YAEGER, *President.*

All moneys received by the Smithsonian Institution from interest, sales, and refunding of moneys temporarily advanced are deposited with the Treasurer of the United States to the credit of the Institution, and all payments are made by checks signed by the secretary.

The expenditures made by the disbursing agent of the Institution and audited by the Auditor for the State and Other Departments are reported in detail to Congress and will be found in the printed document.

Your committee also presents the following summary of appropriations for the fiscal year 1916 intrusted by Congress to the care of the Smithsonian Institution, balances of previous appropriations at the beginning of the fiscal year, and amounts unexpended on June 30, 1916:

	Available after July 1, 1915.	Balance June 30, 1916.
International Exchanges, 1914	$0.01	[1] $0.01
International Exchanges, 1915	3,453.79	.20
International Exchanges, 1916	32,000.00	3,584.17
American Ethnology, 1914	185.30	[1] 176.59
American Ethnology, 1915	3,854.32	1,119.04
American Ethnology, 1916	42,000.00	2,897.78
International Catalogue, 1914	21.50	[1] 21.50
International Catalogue, 1915	884.45	196.39
International Catalogue, 1916	7,300.00	549.81
Astrophysical Observatory, 1914	62.36	[1] 62.36
Astrophysical Observatory, 1915	1,263.57	46.35
Astrophysical Observatory, 1916	13,000.00	1,522.31
Bookstacks, Government bureau libraries, 1914	33.61	[1] 33.61
Bookstacks, Government bureau libraries, 1915	35.36	1.09
Bookstacks, Government bureau libraries, 1915–16	[2] 6,500.00	64.15
Tower telescope on Mount Wilson, 1915	1,294.17	410.23
Repairs to Smithsonian Building, 1915	452.13	176.86
National Museum:		
Furniture and fixtures, 1914	56.85	[1] 56.85
Furniture and fixtures, 1915	1,048.82	13.34
Furniture and fixtures, 1916	25,000.00	1,941.95
Heating and lighting, 1914	242.62	[1] 242.62
Heating and lighting, 1915	4,473.32	109.63
Heating and lighting, 1916	46,000.00	5,862.65
Preservation of collections, 1914	573.78	[1] 509.15
Preservation of collections, 1915	8,774.88	1,278.34
Preservation of collections, 1916	300,000.00	7,695.91
Books, 1914	26.22	[1] 10.30
Books, 1915	1,389.73	115.00
Books, 1916	2,000.00	1,157.49
Postage, 1916	500.00	....
Building repairs, 1914	5.03	[1] 5.03
Building repairs, 1915	487.15	1.32
Building repairs, 1916	15,000.00	2,298.58
National Zoological Park, 1914	3.94	[1] 3.94
National Zoological Park, 1915	6,251.07	.83
National Zoological Park, 1916	100,000.00	3,652.99
Bridge over Rock Creek, National Zoological Park	1,820.90	[1] 1,820.90

[1] Carried to credit of surplus fund.

[2] Immediately available.

Statement of estimated income from the Smithsonian fund and from other sources, accrued and prospective, to be available during the fiscal year ending June 30, 1917.

Balance June 30, 1916		$44, 711. 02
Interest on fund deposited in United States Treasury due July 1, 1916, and Jan. 1, 1917	$60, 451. 00	
Interest on West Shore Railroad bonds due July 1, 1916, and Jan. 1, 1917	1, 680. 00	
Exchange, repayments, sale of publications, refund of advances, etc	7, 526. 04	
Deposits for specific purposes	12, 000. 00	
		81, 657. 04
Total available for year ending June 30, 1917		126, 368. 06

Respectfully submitted.

George Gray,
Alexander Graham Bell,
Ernest W. Roberts,
Executive Committee.

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE FISCAL YEAR ENDING JUNE 30, 1916.

ANNUAL MEETING, DECEMBER 9, 1915.

The Board of Regents met at the Smithsonian Institution in regular annual session at 10 o'clock a. m. December 9, 1915.

Present: The Hon. Edward D. White, Chief Justice of the United States, chancellor, in the chair; Senator Henry Cabot Lodge; Senator William J. Stone; Senator Henry F. Hollis; Representative Scott Ferris; Representative Ernest W. Roberts; the Hon. Maurice Connolly; Dr. Andrew D. White, Dr. A. Graham Bell; the Hon. George Gray; Mr. John B. Henderson; the Hon. Charles W. Fairbanks; and the secretary, Dr. Charles D. Walcott.

APPOINTMENT OF REGENT.

It was announced that William J. Stone, Senator from Missouri, had been reappointed a Regent by the Vice President on February 18, 1915.

RESOLUTION RELATIVE TO INCOME AND EXPENDITURE.

On motion by Judge Gray, chairman of the executive committee, the following resolution was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1917, be appropriated for the service of the Institution, to be expended by the secretary with the advice of the executive committee, with full discretion on the part of the secretary as to items.

VACANCY IN EXECUTIVE COMMITTEE.

On motion it was—

Resolved, That Mr. Ernest W. Roberts be elected to the executive committee to fill the vacancy caused by the retirement of Mr. Maurice Connolly.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

The annual report of the executive committee reviewing the financial condition of the Institution for the fiscal year ending June 30, 1915, was presented in printed form and adopted.

ANNUAL REPORT OF THE PERMANENT COMMITTEE.

The permanent committee presented the following statement:

Hodgkins fund.—A third allotment of $5,000 was made from the income of this fund for the purpose of continuing the work of the Langley Aerodynamical Laboratory.

Poore bequest.—Mr. John J. Pickman, executor of the estate of George W. Poore, was given an indemnity bond to guarantee him from loss, and he thereupon paid to the Institution the sum of $24,534.92, the net proceeds of the estate, exclusive of certain parcels of land, which are estimated to have a value of $10,000.

The Addison T. Reid bequest was made for the purpose of founding a chair in biology as a memorial to the testator's grandfather, Asher Tunis, subject to the condition that the income be paid in three shares to certain enumerated beneficiaries until their death, when the principal of the estate, with accumulations, was to come to the Institution. As previously reported, one of the beneficiaries died in 1913, and the amount of her share, $4,795.91, was duly received by the Institution. A second beneficiary died during the summer of 1915, and her share, amounting to $4,698.59, was also received.

Rhees bequest.—Mr. William Jones Rhees, chief clerk of the Institution for nearly 40 years, died March 18, 1907, bequeathing to the Institution the sum of $500. This bequest has been received and will be allowed to increase by the addition of its earnings to the principal until a sufficient sum shall have been realized to make possible the provision of a suitable work of some kind to serve as a memorial to this able and faithful official.

Chamberlain bequests.—The board was informed at a previous meeting that Dr. Leander T. Chamberlain had made two bequests to the Institution, each to be known as "the Frances Lea Chamberlain Fund."

The first bequest was $25,000, the income of which was to be used "for promoting the increase and the scientific value and usefulness of the collection of gems and gem material known as the 'Isaac Lea Collection' in the department of minerals in the United States National Museum."

The second bequest was $10,000, the income to be used "for promoting the scientific value and usefulness of the collection of mollusks known as the 'Isaac Lea Collection,'" also in the National Museum. This second bequest has been received.

Sanford bequest.—A bequest of $1,020 has been received by the Institution under the will of Mrs. Helen B. Sanford for the purpose of founding "the George H. Sanford fund," as a memorial to her husband. The income of this fund is to be used for the increase and

diffusion of knowledge on such subjects as the Institution may decide upon.

On motion the report of the permanent committee was accepted.

SECRETARY'S ANNUAL REPORT.

The secretary presented his annual report in printed form and made statements thereon as follows:

The Smithsonian Institution and its branches since the last annual meeting of the Regents have issued a total of 93 publications aggregating about 8,000 pages and 550 plates. Twenty-four of these publications (1,595 pages and 180 plates) were issued by the Institution proper; 66 of them (5,370 pages and 380 plates) by the National Museum; and 3 (1,103 pages and 6 plates) by the Bureau of American Ethnology. The total number of all publications distributed during the year was 145,272. In addition, the annual report of the American Historical Association and of the National Society of the Daughters of the American Revolution were examined by the Institution and transmitted to the Congress.

From among valuable contributions to nearly every branch of science covered in these various publications, may be mentioned as of special interest two papers issued by the Institution proper under the Hodgkins fund, one, an extended study of the radiation of the atmosphere, the other, a paper on the intensity of solar radiation outside the atmosphere. In the course of experiments covered by the latter, free balloons with recording apparatus reached altitudes up to 15 miles and were recovered with the records in good condition. Another paper of considerable interest to physicists and chemists is entitled "A magneton theory of the structure of the atom," by A. L. Parson.

Among National Museum publications there was issued from the United States National Herbarium a Flora of New Mexico, which describes some 3,000 species of plants from that State.

There was also printed the usual pamphlet on explorations and researches by the Smithsonian Institution and its branches, written in a semipopular style and containing numerous illustrations.

Last year there was published a work giving some results of the secretary's studies in Pre-cambrian Algonkian algal flora, and there has been prepared for the current annual report a general review of the secretary's field and laboratory work in Cambrian geology during several years past.

The Annual Report of the Institution for 1914 was completed considerably earlier than for any previous year. The general appendix contains 30 papers relating as usual to all branches of science. The public demand for the Smithsonian Report has become so great

that Congress authorized the edition to be increased from 7,000 to 10,000 copies.

THE LANGLEY AERODYNAMICAL LABORATORY.

At the annual meeting of the Board of Regents, held December 10, 1914, a resolution was adopted providing for the appointment by the chancellor of a committee of four members of the board and the secretary "to consider questions relative to the Langley Aerodynamical Laboratory." The following committee was appointed: Dr. Alexander Graham Bell, chairman; Hon. William J. Stone, Hon. Ernest W. Roberts, Mr. John B. Henderson, and the secretary.

This committee presented a report to the board on the history of the organization of the laboratory under the authority of the Regents and on the need of a National Advisory Committee on Aeronautics; also a statement of American agencies, resources, and facilities for the work, and of the progress made by other nations in this subject. In addition a report was made on the action taken by Congress authorizing the appointment of an advisory committee by the President of the United States, who subsequently selected such committee as follows:

Gen. George P. Scriven, United States Army, and Lieut. Col. Samuel Reber, United States Army, representing the Army; Capt. Mark L. Bristol, United States Navy, and Naval Constructor H. C. Richardson, United States Navy, representing the Navy; Mr. Charles F. Marvin, Chief United States Weather Bureau; Dr. S. W. Stratton, Director United States Bureau of Standards; Mr. Byron R. Newton, Assistant Secretary United States Treasury; Prof. W. F. Durand, Stanford University of California; Prof. Michael I. Pupin, Columbia University, New York City; Prof. John F. Hayford, Northwestern University, Illinois; Prof. Joseph S. Ames, Johns Hopkins University, Baltimore, Md.; Dr. Charles D. Walcott, Secretary Smithsonian Institution.

The committee's report stated further that it was not deemed probable, in view of the organization and scope of the National Advisory Committee for Aeronautics, that the Smithsonian Institution would find it necessary to establish an aerodynamical laboratory for experimental purposes. Its function would now be more in the direction of aiding in such studies and experiments as could not well be otherwise provided for and in publishing such material as might be of value in the development of the art.

On motion, the report was accepted.

In this connection the secretary stated that the experiments being conducted with the Langley aerodrome on Lake Keuka, New York, were successfully continued during the year 1915 and that a report

thereon had been filed in the office by Dr. A. F. Zahm; that the National Advisory Committee for Aeronautics had approved of the cooperation between the Smithsonian Institution and the United States Weather Bureau in connection with the investigations of the atmosphere having a bearing upon aeronautics, and that this cooperation had met with the approval of the Secretary of Agriculture and of the Chief of the Weather Bureau. To carry this into effect, $2,500 had been set aside from the allotment for the Langley Aerodynamical Laboratory for the purchase of necessary instruments, sounding balloons, etc., and for conducting such experiments as could not be provided for from funds of the Weather Bureau.

Site for Freer Gallery of Art.—At the last meeting of the board a resolution was adopted authorizing the chancellor to appoint a committee to consider the matter of a site for the proposed Freer Building, and the following were appointed on said committee: Senator Lodge, Senator Hollis, Judge Gray, Mr. Connolly, and the secretary.

The committee presented a report recommending that the building be erected on a site in the southwest corner of the Smithsonian grounds, west of the Smithsonian building, and south of the line recommended by the National Park Commission in 1906 for future buildings on the Mall.

The committee's recommendation was approved by the board.

In this connection the secretary read an extract from Mr. Freer's letter of December 4, stating that if the board took favorable action he would at once place at the Institution's disposal the $1,000,000 he had already set aside for this purpose.

The secretary referred to the Widener art collection and to the newspaper comments as to the possibility of securing the collection for Washington City. These art objects were left to Mr. Widener's son with discretion as to donating them to Philadelphia, Washington, or New York. The collection is now handsomely housed, and the secretary very much doubted that any action would be taken toward its being placed elsewhere for many years to come.

Speaking on the subject of the National Gallery of Art, the secretary mentioned the art collections already in the custody of the Institution and said that the time will soon be here when definite action must be taken looking to their proper housing.

Bird and animal refuges.—The secretary stated that he had given considerable attention to the development of the movement for the creation of bird refuges, and that he had called the attention of the executive committee to an inquiry that had been made as to whether the Smithsonian Institution would consider the acceptance of a large tract of land on the coast of the Gulf of Mexico for the administration of a great bird and wild animal refuge.

The board decided that gifts of lands, buildings, or funds to establish bird or wild animal refuges might be accepted and administered, on condition that adequate provision for their proper maintenance be made by the donor or donors or other agencies.

SECRETARY'S STATEMENT.

The secretary also made the following statements:

The National Gallery of Art received in July, 1915, a collection of pictures which, though not of an elaborate nature, is remarkable for the long list of eminent artists represented. The collection consists of 82 drawings executed with various mediums, principally water color, crayon, charcoal, pencil, chalk, and pen, by as many of the most prominent contemporary painters, sculptors, and engravers of the French Republic. It came as a testimonial from the people of France to the people of the United States in recognition of their sympathetic efforts toward relieving the distress and suffering in France occasioned by the war in Europe and is the result of action by an organizing committee in Paris begun in March, 1915. The collection was delivered to the American ambassador at the French capital early in July, and immediately upon its receipt at the Department of State in Washington it was deposited in the National Gallery.

A catalogue of the collection has been printed and widely circulated, and it constitutes a most distinguished honor roll. Of added interest is the fact that the pictures are all signed, and, with very few exceptions, each is also inscribed by the artist with an expression of friendly feeling and gratitude.

Bureau of American Ethnology.—During the summer and autumn of 1915 important archeological excavations were conducted in the historic Nacoochee Mound in White County, Ga., as well as in the Mesa Verde National Park of southern Colorado, where a large ruin exhibiting remarkable masonry was thoroughly excavated and repaired.

Ethnologic investigations among the Creek and Natchez Indians of Oklahoma, the Fox Indians of Iowa and Oklahoma, and the Chumash and Mohave Indians of California, were prosecuted in the field with excellent results, and equally successful efforts were made in studying the languages of some of the tribes of Oregon that are threatened with extinction.

A reconnaisance of the ruins of pueblos in the Zuni Valley, New Mexico, was made with a view to their excavation during the summer of 1916.

Addition of land to the National Zoological Park.—The sundry civil act for the fiscal year ending June 30, 1914, appropriated

$107,200 for the purchase, as an addition to the National Zoological Park, of land lying between the present western boundary of the park and Connecticut Avenue, between Cathedral Avenue and Klingle Road.

After many delays in the legal steps to acquire this land, the jury of condemnation presented its findings to the court on December 11, 1914, as follows:

Damages appraised	$194, 438. 08
Expenses of jury	2, 203. 35
Total	196, 641. 43
Benefits assessed at	66, 013. 50
Excess of damages over benefits	130, 627. 93
This sum exceeds the appropriation by	23, 427. 93

On January 12, 1915, the motion of the Secretary of the Treasury to confirm the verdict was received by the court and filed. From time to time exceptions to the verdict were filed by various property owners interested, and on June 28, 1915, the court set aside the verdict of the assessment of benefits and costs as regards exceptors and confirmed the remainder of the assessments and the awards of damages.

A recent statement from the Assistant United States Attorney for the District shows that the benefits assessed by the jury that have been set aside by the court amount to approximately $48,000, and that, according to his figures, the total amount that will be required to secure the land will be approximately $179,000 instead of the $107,200 as appropriated.

The land in question has a frontage on Connecticut Avenue of 1,750 feet and covers about 10 acres, which if obtained will bring the park area to an aggregate of 180 acres.

Notes on the recent work of the Astrophysical Observatory.—Dr. Charles G. Abbot, director, and Mr. L. B. Aldrich, assistant, have continued at Mount Wilson, Cal., their observations on the intensity of solar radiation.

Complete reductions of the Mount Wilson work of 1914 show that the return of solar activity in that year—after the passage of the minimum epoch of 1913 (in which sun spots had become fewer than at any time for a century)—was attended by a very considerable rise in the intensity of solar radiation. Work with the tower telescope on Mount Whitney was continued, and this also confirmed the variability of the sun.

It is greatly regretted that no other observing station had been equipped to share with the Institution these observations on the variation of the sun. Only when several observatories, widely scattered in favorable regions as regards weather conditions, shall unite to

follow these observations from day to day for several years can the results be of much value to meteorologists as evidence whether or not the sun's variability influences terrestrial climate. The Institution is looking forward to establishing and operating a station in Argentina or some other favorable situation in South America, the expense to be provided for from the income of the Hodgkins fund.

A new vacuum bolometer has been devised which in actual trial developed 20 times the sensitiveness of the bolometer heretofore used on Mount Wilson for these researches. With this new bolometer at least one ten-millionth of a degree rise of temperature could be detected and measured, and it seems not impossible that a bolometric outfit could be constructed capable of detecting and measuring even a billionth of a degree rise of temperature.

The Research Corporation.—The Research Corporation has successfully continued its work during the year and is now on a sound financial basis. On October 31, 1915, the assets of the corporation were $166,004.23. In these assets the Cottrell process patents are valued at the nominal sum of $1,000.

It will be recollected that the Research Corporation was organized in February, 1912, with a capital of $10,000 and a salary roll of less than $3,000. The salary roll for the ensuing year, owing to the great increase in the scope of the work, will be in the neighborhood of $38,000.

The energies of the corporation have been almost entirely applied in connection with the experimental precipitation processes which, it will be recalled, were offered to the Smithsonian Institution by Dr. Cottrell, and by it in turn offered to the Research Corporation for commercial development. If the successful development of the organization continues other lines of research will be entered upon.

Electrical precipitation of fog.—Under a grant of $2,000 made by the Institution from the Hodgkins fund Dr. F. G. Cottrell has conducted experiments at the Panama-Pacific Exposition at San Francisco in relation to the electrical precipitation of fog. The secretary, while visiting the exposition, saw something of the experiments and examined the apparatus used. The most striking features of the apparatus are the Thordarson 350,000 and 1,000,000 volt transformers placed at the service of Dr. Cottrell. These experiments involved the cooperation of the Panama-Pacific Exposition officials, the Research Corporation, Mr. C. H. Thordarson, the University of California, the General Electric Co., and the Smithsonian Institution.

The problem of clearing fog differs from other precipitation problems in several respects. For instance, in the latter cases it is manifestly necessary to actually deposit the suspended matter on the electrodes in order to accomplish the effect sought, while in the case of

fog, if even a considerable coalescence of the minute particles into large ones could be effected, it would become much more transparent, even aside from the more rapid settling of the drops. New difficulties are to be expected, however, such as the matter of insulation, for the reason that the whole apparatus is of necessity continuously immersed in the wet atmosphere.

Harriman trust fund.—Dr. C. Hart Merriam, operating under the trust fund established by Mrs. E. H. Harriman, has continued the study of the Big Bears of North America, and the preparation of manuscript and illustrations for the press. Owing to the scarcity of specimens of some of the less known species, final effort was made to obtain additional skulls, and more than 50 were secured which have proved of value in clearing up points previously in doubt as to the characters of several of the species.

The labor of searching the literature relating to early exploration, hunting, and travel for records of bear and other animals, has been continued, and large additions have been made to the files of material relating to North American mammals and to the Indian tribes of California and Nevada.

Borneo and Celebes expedition.—As previously stated, Dr. W. L. Abbott, a collaborator of the National Museum, contributed $11,000 in money and between $500 and $1,000 in ammunition and supplies for the purpose of conducting a collecting expedition in Borneo and Celebes. Mr. Henry C. Raven, Dr. Abbott's personal representative in this enterprise, spent about two years in Borneo and nearly a year in Celebes. He returned to Washington during the summer of 1915. The expedition has been briefly described in a pamphlet recently issued by the Institution. Its main results include a collection of 465 mammals, 870 birds, 50 reptiles, and a miscellaneous series of ethnological and zoological material.

Dr. Abbott has recently added to his generous gifts a donation of $2,000 to provide for a second expedition to make natural history collections and explorations in the Dutch East Indies, particularly in Celebes. Mr. Raven was selected for this new expedition, and after outfitting at Washington, he sailed October 19, 1915, from Seattle for the field of his new operations via Singapore. The expedition is expected to last about three years, and the results will be presented to the National Museum.

Siberian Expedition.—As previously reported, an expedition to Siberia was financed by the Telluride Association, of Ithaca, N. Y., which generously donated $3,500 for the purpose. The expedition was under the direction of Capt. John Koren, who was accompanied by Mr. Copley Amory, jr., a collaborator of the National Museum, and by Mr. Benno Alexander, who specially represented the Smithsonian Institution.

The party sailed from Seattle on June 26, 1914, and after an exploration of the territory about the Kolyma River region, Mr. Amory returned during the summer of 1915 bringing 365 mammals and 264 birds. This collection was obtained at the nominal cost of an outfit and the transportation from Nome, Alaska, to Washington, and is a very important contribution to the National Museum.

Biological work in North China.—Mr. A. de C. Sowerby is continuing his work in Manchuria and northeastern China through the generosity of a friend of the Smithsonian, whose identity, as heretofore reported, is withheld. Two wapiti bucks and a roe deer have been received, but the main collections have been delayed in transit.

Montana and Wyoming.—The secretary continued his work of exploration among the fossil beds of Montana in connection with his studies of the early life of the earth. In the Yellowstone National Park he observed the character and method of deposition of the hot spring and geyser deposits by the primitive blue-green algæ, and supervised the collecting of siliceous geyserite, silicified wood, and volcanic rocks. Over 5 tons of material were shipped to the National Museum during the summer of 1915.

On leaving the park the canyon of the West Gallatin River was followed for a distance of 30 miles, and the valley of the upper Missouri River was crossed at Townsend, Mont., en route to the Belt Mountains. A collection of very ancient fossil algal remains was made there, of which one and a half tons of specimens were selected for study in connection with the material obtained during the field season of 1914. These specimens contain the oldest fossil bacteria known, as well as deposits similar to those made by the blue-green algæ in the Yellowstone National Park hot springs.

Throughout the trip Dr. Walcott was assisted by Mrs. Walcott, who is an enthusiastic photographer and collector.

Dr. Hrdlička's proposed Asiatic expedition.—The object of the contemplated expedition is to trace in eastern Asia, as far as may be possible, the origin of the American aborigines, which is now one of the foremost problems before the anthropologists of the world. A preliminary survey of parts of Siberia and Mongolia, made by Dr. Hrdlička under the auspices of the Smithsonian Institution in 1912, yielded results of the most interesting nature, and the evidence, ethnological and archeological, encouraged the belief that further research would lead to determinations of great scientific value. The primitive tribes visited by Dr. Hrdlička are, in their physical characteristics, hardly to be distinguished from the typical American Indian and the traces of prehistoric culture give almost equally close analogies, and it seems most desirable that further explorations should be undertaken.

The great group of peoples concerned and to be studied are distributed over Tibet, western China, Mongolia, Manchuria, Korea, Japan, and a large part of Siberia, and extend in varying degrees of relationship to Polynesia, Malaysia, and the Philippine Islands. The special object of Dr. Hrdlička's proposed expedition is to definitely trace this distribution in its relation to the peopling of the American Continent. It is anticipated that the proposed survey should extend over four or five years.

Mr. Warner's proposed expedition to eastern Asia.—An expedition which is expected to cooperate in important ways with that of Dr. Hrdlička, but which will devote its main attention to the prehistoric and early historic archeology and art of eastern Asia, is contemplated by Mr. Langdon Warner. Mr. Warner plans to explore certain districts of southern China, excavating mounds and ruined cities which are confidently expected to yield archeological and art treasures of exceptional value. Doubtless these excavations will result in the recovery of large quantities of skeletal remains and of objects of primitive art, which placed in the hands of specialists in these branches will serve to throw much light on the ancient peoples of Asia.

This expedition is undertaken under the auspices of the new Cleveland Museum of Art.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1916.

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the secretary, induced in part by the discontinuance of an annual summary of progress which for 30 years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1916.

ADMINISTRATION AND ACTIVITIES OF THE SMITHSONIAN INSTITUTION.

By A. Howard Clark,
Editor, Smithsonian Institution.

[With 22 plates.]

THE ESTABLISHMENT—BOARD OF REGENTS.

The Smithsonian Institution was created by act of Congress, in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and therefore constituted an "establishment," whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments." The business of the Institution is conducted by a Board of Regents composed of "the Vice President, the Chief Justice of the United States, and three Members of the Senate and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of them of the same State." The Regents elect one of their number as chancellor, usually the Chief Justice, who is the presiding officer of the board, and elect a suitable person as secretary of the Institution, who is also secretary of the board and the executive officer and director of the Institution's activities.

RESOURCES.

The annual income of the Institution is about \$100,000, derived from interest on the permanent fund (in the United States Treasury) and on special funds, and contributions from various sources, which is applied to operations of the Institution proper, besides annual congressional appropriations of about \$600,000 for the main-

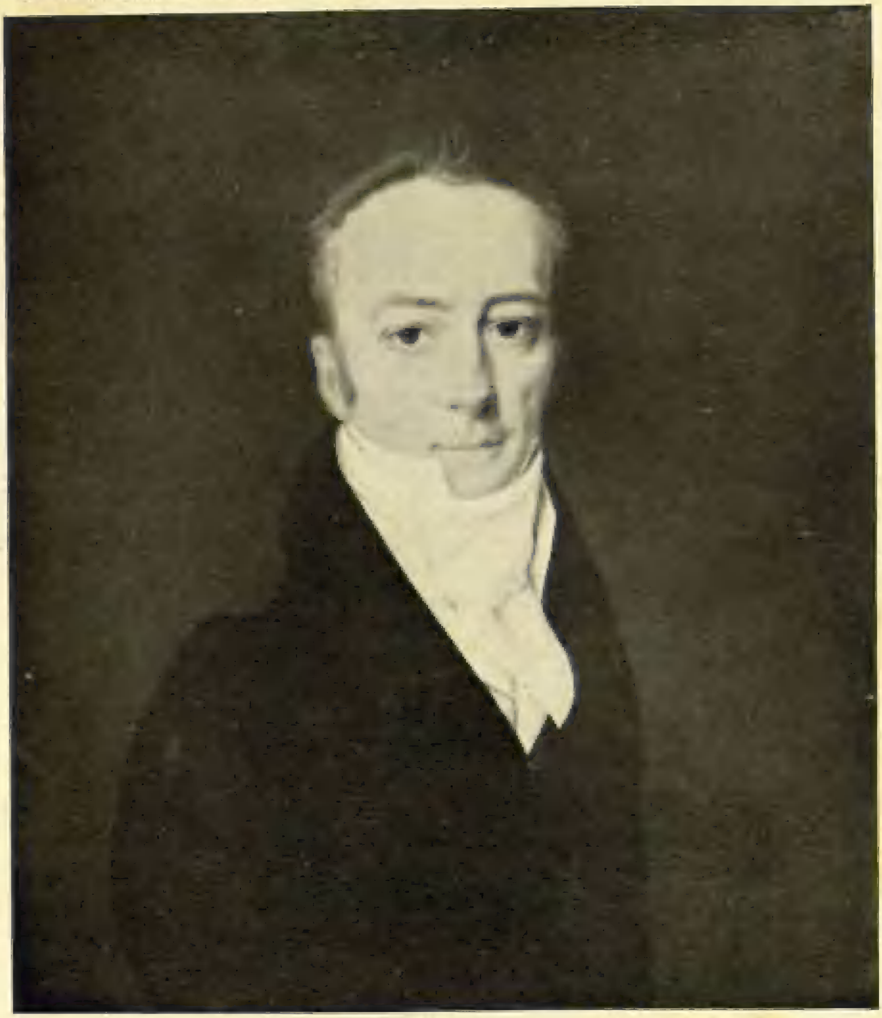
tenance of the bureaus or branches of the Institution developed through its early activities, including the United States National Museum and the National Gallery of Art, the International Exchange Service, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, and the United States Bureau of the International Catalogue of Scientific Literature. The Regents are empowered to accept gifts without action of Congress in furtherance of the purposes of the Institution, and to administer trusts in accord therewith. Many important researches and expeditions, particularly during recent years, have also been aided by special trusts provided by patrons of the Institution. Among the most notable of these explorations, financed through private donations, was the African expedition under Theodore Roosevelt, and explorations in the Far East continued for several years past through the liberality of Dr. William L. Abbott. The income of certain trust funds is set aside for specific purposes, as that of the Frances Lea Chamberlain fund for the maintenance of the Isaac Lea collections of gems and mollusks, and that of a fund established by Mrs. E. H. Harriman for carrying on certain biological studies; also the income of a portion of the Hodgkins fund, devoted to the study of atmospheric air.

SMITHSONIAN BUILDINGS.

The buildings occupied by the Institution and the National Museum are in the Smithsonian Park, an area of 38 acres about midway between the Capitol and the Washington Monument. The original Smithsonian building is of brownstone in twelfth century Norman or Lombard style of architecture, 447 feet front and covering about 60,000 square feet. It was completed in 1855. The administrative offices are here, as also several sections of the library, the Museum division of plants or National Herbarium, and the division of graphic arts, also the offices and library of the Bureau of American Ethnology.

Adjacent to the administrative building on the east is the Museum of Industrial Arts, built of brick in modernized Romanesque style of architecture, covering about 2½ acres, and completed in 1881. Here are exhibited objects relating chiefly to the arts and industries and American history.

On the north side of the park is the Museum of Natural History, completed in 1911. This fine structure is of granite in modern classic style with dome and columned portico. It covers an area of about 4 acres and in its ground floor and the three stories there are 468,118 square feet of floor space, one-half of which is devoted to exhibition purposes, the other half being utilized for storage rooms, offices,



JAMES SMITHSON.

SMITHSONIAN BUILDING.

ARTS AND INDUSTRIES BUILDING, U. S. NATIONAL MUSEUM.

NATURAL HISTORY BUILDING, U. S. NATIONAL MUSEUM. SOUTH FRONT.

laboratories, and other purposes. As the latest of the great museum buildings of the world it embodies many new and important features. Here are displayed the collections pertaining to anthropology, biology, and geology, and the National Gallery of Art.

The number of visitors to the original Smithsonian building from 1881 to 1916 was 4,580,932; and to the industrial arts building 7,727,732; while the visitors to the natural history building from 1910 to 1916 numbered 1,835,529.

Through the generosity of Mr. Charles L. Freer there was begun in the summer of 1916 in connection with the National Gallery of Art, the construction of a beautiful edifice to house the splendid collection of American and oriental works of art presented to the Institution by Mr. Freer, who has placed at the disposal of the Institution more than a million dollars to defray the cost of the building.

The Astrophysical Observatory is housed in a group of small wooden structures south of the Smithsonian administrative building.

PURPOSES AND OBJECTS.

The Smithsonian plan of organization embraces the two objects named by the testator; one, the increase of knowledge by the addition of new truths to the existing stock; the other, the diffusion of knowledge, thus increased, among men. No restriction is made in favor of any kind of knowledge, and hence each branch is entitled to and receives a share of attention. Part of the plan has included the formation of a library of science and art, a museum, a gallery of art, and provisions for physical research and popular lectures.

The activities of the Institution embrace all branches of natural science, the fine arts, and industrial arts. It has at all times fostered progressive scientific research. Since its establishment the Institution has inaugurated and maintained or has participated in a great number of astronomical, anthropological, biological, and geological expeditions and explorations in every portion of the world, resulting in largely increasing our knowledge of the geography, the meteorology, the fauna and flora, and the ethnology of all lands, and in the acquisition of a vast amount of valuable material for the National Museum.

The Smithsonian is not an educational institution of the nature of a university with a corps of professors and students, and yet its educational functions are of the highest rank, for the members of its scientific staff and its many collaborators are constantly engaged in investigations in which students of science in all its branches participate; and the museum collections and the collection of animals in the Zoological Park are a constant source of original infor-

mation to specialists and to groups of pupils from public and private schools in Washington and elsewhere.

The Institution aids investigators by making limited grants for research and exploration. It advises the Government in matters of scientific importance. It cooperates with all departments of the Government and with many scientific and historical national organizations.

ACTIVITIES AND ACHIEVEMENTS.

The Regents controlling the policy and conducting the operations of the Institution have always been men well known in public life and in the educational and scientific world.

Among the more than 150 eminent Americans who have guided Smithsonian activities in past years may be mentioned Louis Agassiz, the naturalist; Alexander Dallas Bache; George Bancroft, the historian; Salmon Portland Chase; Rufus Choate; James Dwight Dana, the eminent geologist and mineralogist; Asa Gray, the botanist; Gen. Montgomery C. Meigs, engineer; President Noah Porter, of Yale University; Lieut. Gen. William Tecumseh Sherman; and many other men prominent in science and art and in public affairs in more recent years who are still active as Regents or patrons or otherwise vitally interested in the work of the Institution.

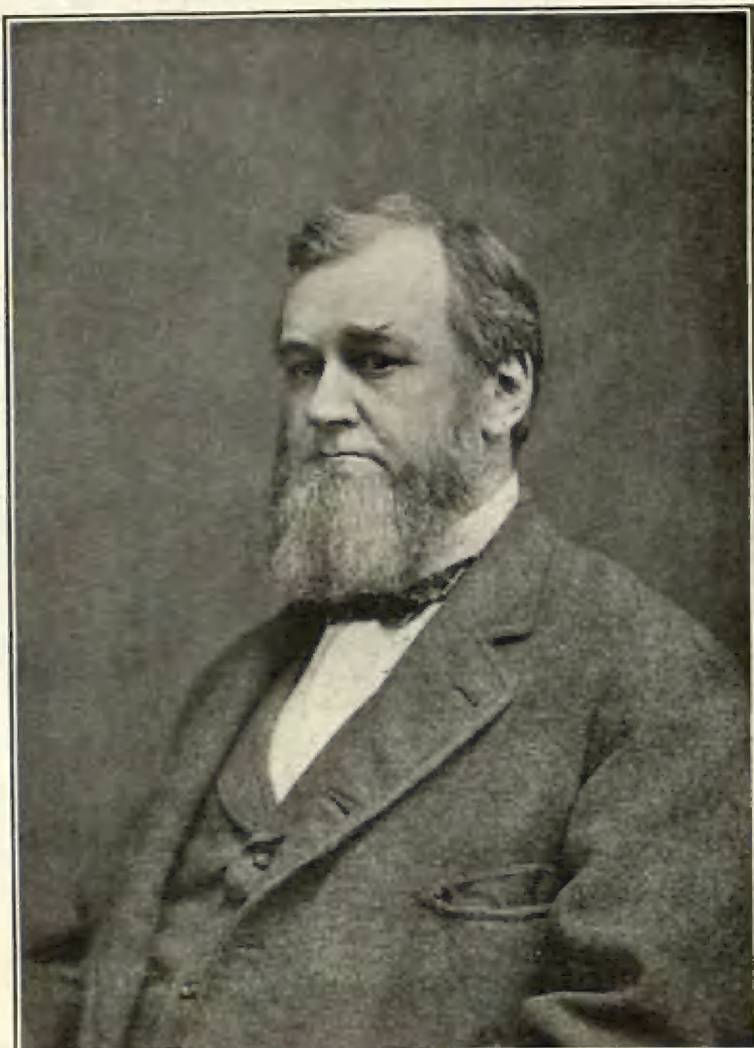
Under such leadership the achievements in every branch of knowledge have been notable and numerous. The Institution is practically the parent of many of the scientific bureaus of the Government. Here were begun researches in astronomy, physics, meteorology, geology, botany, fisheries, aviation, and other lines, some of which, having outgrown facilities and means immediately available to the Institution, have been developed into separate Government bureaus, including the United States Weather Bureau, the United States Geological Survey, the Fisheries Bureau, the National Advisory Committee for Aeronautics, and other Federal bureaus, with all of which the Institution continues in close and constant cooperation. To some of these bureaus now belong the more economic phases of scientific work, while the Institution devotes its energies largely to the fundamental work, researches in the domain of pure science, keeping in view, however, the bearing of these researches on the welfare of mankind.

To Joseph Henry, Secretary of the Institution, 1846 to 1878, eminent as a physicist, the world of science and industry owes a lasting debt, for it was he who in great measure made possible the electrical achievements of the present day. "He married the intensity magnet to the intensity battery, the quantity magnet to the quantity battery, discovered the law by which their union was effected, and rendered their divorce impossible." The intensity magnet is that which is to-

NATURAL HISTORY BUILDING, U. S. NATIONAL MUSEUM. NORTHWEST CORNER.

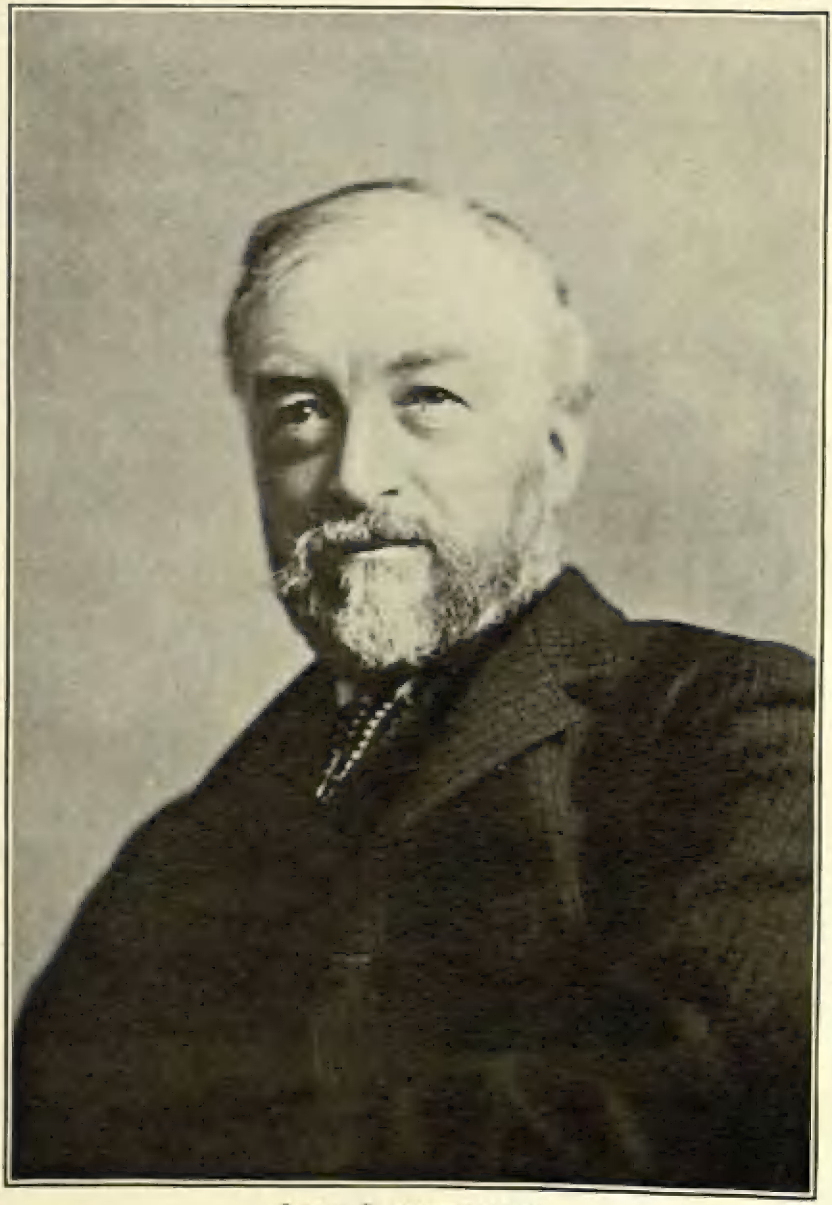
JOSEPH HENRY,

Secretary of Smithsonian Institution, 1846-1878.



SPENCER FULLERTON BAIRD,

Secretary of Smithsonian Institution, 1878–1887.



SAMUEL PIERPONT LANGLEY,

Secretary of Smithsonian Institution, 1887–1906.

day in use in every telegraph system. "Henry's oscillating machine was the forerunner of all our modern electrical motors. The rotary motor of to-day is the direct outgrowth of his improvements in magnets." His name is perpetuated in the term "henry," the unit of electric inductance.

Henry also inaugurated the system of daily meteorological observations, out of which grew the United States Weather Bureau, and, as head of the Lighthouse Board, he revolutionized the methods of lighthouse operation and signaling.

In 1847 the Institution made an appropriation "for instruments and other expenses connected with meteorological observations." The instruments thus secured were distributed throughout the country, and within two years the volunteer observers reporting to the Institution numbered about 400. In 1849 Henry realized the value of the electric telegraph as "a ready means of warning the more northern and southern observers to be on the watch for the first appearance of an advancing storm," and there was inaugurated a system of daily telegraphic weather reports, a system which was continued under the direction of the Institution until the beginning of the Civil War. On a large map in the Smithsonian building the weather over a considerable part of the country, according to reports received at 10 o'clock each day, was indicated by suitable symbols.

Spencer Fullerton Baird, Secretary, 1878 to 1887, noted as a biologist, during his administration bent his energies to increase man's knowledge of animal life. He established the United States Commission of Fish and Fisheries, now known as the Bureau of Fisheries, for the study of food fishes and river and ocean fauna. Secretary Baird, as keeper of the Museum, took a deep interest in the national collections in natural history and other objects, and under his direction there was erected the Museum building for the exhibition of the valuable collections acquired from the International Exhibition at Philadelphia in 1876. During his administration the National Museum was rapidly developed under the direction of Assistant Secretary G. Brown Goode, and the need for more adequate quarters soon became evident.

Samuel Pierpont Langley, Secretary, 1887 to 1906, won eminence by his achievements as an astronomer, especially by his astrophysical observations and discoveries, and he became known to the world at large through his 18 years of administrative service as Secretary of the Smithsonian Institution. His fame will also become increasingly greater as the new science of aviation is further developed, for to Langley belongs the honor of being the first to demonstrate to the world, in 1896, the practicability of mechanical flight with machines heavier than the air, sustained and propelled by their own power,

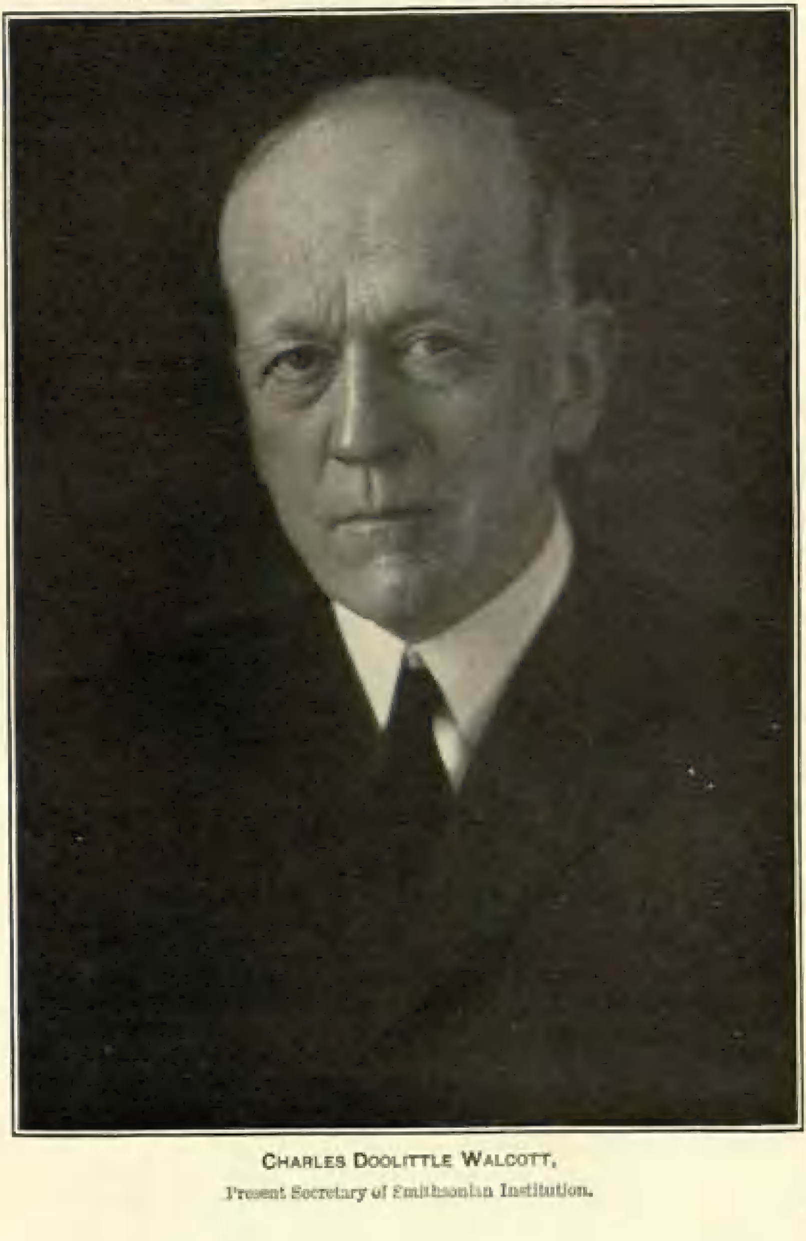
and he later developed and built the first man-carrying aeroplane capable of sustained free flight. Langley's success as a pioneer in aviation was commemorated on the Column of Progress at the Panama-Pacific International Exposition by a tablet bearing the inscription: "To commemorate science's gift of aviation to the world through Samuel Pierpont Langley, an American."

It was Prof. Langley who, in 1869, inaugurated a general system of standard-time distribution to various cities and railroads, a system which in 1885 had extended to 4,713 miles of railroad and is now universal throughout the country.

He devised that most delicate instrument—the bolometer or electrical thermometer—by which changes of temperature of less than the hundred-millionth of a degree centigrade are measured, and by special installation differences in temperature amounting to one-billionth of a degree can be detected. Langley's investigations in radiation include (*a*) the distribution of radiation over the sun's surface and in sun spots, (*b*) the solar energy spectrum and its extension toward the infra red, (*c*) the lunar energy spectrum and the temperature of the moon, (*d*) spectra of terrestrial sources and determination of hitherto unmeasured wave lengths, and (*e*) the absorption by the earth's atmosphere of the radiation of the sun and the determination of the solar constant of radiation. In each of these lines of research important discoveries were made by Langley, and since his death the work has been greatly advanced through the present director of the Smithsonian Astrophysical Observatory, Dr. Charles Greeley Abbot.

It was during the administration of Secretary Langley that the National Zoological Park, largely the outgrowth of investigations on living animals under the direction of Assistant Secretary G. Brown Goode, was founded, and during this period there was begun the erection of the present great structure for the natural history collections of the National Museum, a building planned under the direction of Assistant Secretary Richard Rathbun, who had made careful studies of the principal museums of the world.

Charles Doolittle Walcott, the present Secretary, a geologist and paleontologist, began his administration as Secretary of the Institution in 1907, having been connected with the Museum as an honorary officer of the department of paleontology since 1882. From 1888 to 1907 he held various positions in the United States Geological Survey, being its director from 1894 to 1907. His special study has been Cambrian geology and paleontology, and he has recently succeeded in bringing to light evidences of algal life in the pre-Cambrian Algonkian sediments, as also the discovery of most delicate examples of fossil holothurians and medusæ in Middle Cambrian



CHARLES DOOLITTLE WALCOTT,

Present Secretary of Smithsonian Institution.

HODGKINS MEDAL OF SMITHSONIAN INSTITUTION.

time. His publications have been voluminous in all phases of his specialty.

During his administration the natural history and fine-arts collections have been brought to a high status. The Institution has come into very close affiliation with a number of research corporations and scientific bodies through his official relation in their directorship. He has taken deep interest in the promotion of the art of aviation, being largely instrumental in the establishment by Congress of the National Advisory Committee for Aeronautics, having as one of its primary objects the bringing into close coordination of the Army and Navy and other branches of the Government and private interests engaged in various lines of aeronautical research.

A prominent department of activity throughout the history of the Institution has been the scientific exploration of regions imperfectly known, particularly in North America. Expeditions have been fitted out under the Institution's immediate direction and others organized by private enterprise or by Government departments have been aided by counsel and instructions. The geological work of the Mexican Boundary Survey, the Colorado expeditions of Lieut. Ives, explorations to the Yellowstone, and many expeditions and explorations in Alaska, in the Arctic, in Africa, in Siberia, in South America, in China, in Tibet, and elsewhere have been more or less intimately related with the Smithsonian Institution.

The numerous and important services rendered to botanical science have greatly increased knowledge of the flora of little-known regions, especially in the south and west of this country and in Mexico, and, as a result of numerous investigations and surveys, there has been brought together in the Institution the great National Herbarium of more than 1,000,000 specimens of the flora of the United States and foreign lands.

Recently the Institution has acquired a three years' lease of the Cinchona Botanical Station at Jamaica, comprising about 10 acres of land, with offices, laboratories, and other buildings, for the furtherance of our knowledge of West Indian botany. Assignment of botanists who desire to prosecute studies there are made on the recommendation of organizations which have cooperated with the Institution in securing the use of this important field for botanical investigations.

Under the auspices of the Institution and in cooperation with several departments of the Government, there has been a most thorough biological and geological survey of the Panama Canal Zone, resulting in a great addition to the knowledge of the fauna and flora and the geological history of that region.

As an aid to students of marine life, the Institution for several years has maintained a table at the Naples Zoological Station. The use of the table for stated periods has been accorded to a large number of investigators on the recommendation of a committee appointed to advise the Institution as to the qualifications of applicants for the privilege of using the facilities thus afforded for carrying on their researches.

Many zoological explorations have likewise been carried on or aided by the Institution. Through the influence of the Institution naturalists or collectors were attached to practically all the important early surveys by the engineers of the United States Army, and the vast collections thus brought together have, in the main, been studied within the walls of the Smithsonian buildings and the natural history results made known through Smithsonian publications.

An important feature of the Institution's activities has been its participation in the many international expositions held during the last forty years in the United States and Europe and numerous medals and diplomas of commendatory nature have been received for the exhibits displayed on these occasions, illustrative of the work of the Institution and of the resources and industries of the country and the customs of its people.

In the interest of general education, particularly in natural history and mineralogy, it has been the custom of the Institution to distribute to schools and colleges throughout the country such duplicate material as could be spared from the National collections. These specimens are fully labeled and have aided instruction by supplementing textbook information.

A large addition to the Smithsonian fund was made in 1891 when Thomas G. Hodgkins, of Setauket, N. Y., presented $200,000 to the Institution. The donor was deeply impressed with the importance of a careful study of atmospheric air, and stipulated that the income of $100,000 of his gift should be devoted to the increase and diffusion of more exact knowledge in regard to the nature and properties of atmospheric air in connection with the welfare of man. He indicated his desire that researches be not limited to sanitary science, but that the atmosphere be considered in its widest relationship to all branches of science, referring to the experiments of Franklin in atmospheric electricity and the discovery of Paul Bert in regard to the influence of oxygen on the phenomena of vitality as germane to his foundation. To stimulate researches in these directions the Institution offered a prize of $10,000 for a paper embodying some new and important discovery in regard to the nature and properties of atmospheric air, which was awarded in 1895 to Lord Rayleigh and Prof. William Ramsay, of London, for

the discovery of argon, a new element in the atmosphere. Another prize of $1,000 for the best popular treatise on atmospheric air was awarded to Dr. Henry de Varigny, of Paris, from among 229 competitors in the United States, France, Germany, England, Scotland, Ireland, Italy, Russia, Austria-Hungary, Norway, Denmark, Finland, Bohemia, Bavaria, Servia, Switzerland, Spain, India, Canada, Mexico, and Argentina. Numerous investigations on the "composition of expired air and its effects upon animal life," in "atmospheric actinometry," the "air of towns," "animal resistance to disease," "experiments with ionized air," "the ratio of specific heats," and kindred topics have been carried on with the aid of grants from the Hodgkins fund. Researches have likewise been aided in connection with the temperature, pressure, radiation, and other features of the atmosphere at very high altitudes, and many other lines of investigation have been carried on, through all of which it is believed that valuable knowledge has been acquired by which the welfare of man has been advanced.

HODGKINS AND LANGLEY MEDALS.

The Hodgkins gold medal was established by the Smithsonian Institution to be awarded for important contributions to the knowledge of the nature and properties of atmospheric air, or for practical applications of existing knowledge to the welfare of mankind. It was first bestowed April 3, 1899, on Prof. James Dewar, F. R. S., and second, October 28, 1902, on Prof. J. J. Thomson, F. R. S.

The Langley medal was established in memory of the late Secretary Samuel Pierpont Langley and his contributions to the science of aerodromics, "to be awarded for specially meritorious investigations in connection with the science of aerodromics and its application to aviation." This medal was presented in 1910 to the brothers Wilbur and Orville Wright, and in 1913, to Mr. Glenn H. Curtiss and Mons. Gustave Eiffel.

PUBLICATIONS AND EXCHANGES.

The "diffusion of knowledge," which, next to its "increase," was so prominently in the mind of the founder of the Institution, was provided for in the program of organization, submitted by Secretary Henry to the Board of Regents in 1847, by a system of several series of publications constituting original contributions to knowledge, accounts of scientific explorations and investigations, and papers recording the annual progress in the field of science, which are distributed gratuitously to important libraries throughout the world.

The publications have been numerous and include many important and authoritative works. There is no restriction as to subject; they consist of memoirs upon aeronautics, archeology, astronomy, astrophysics, ethnology, botany, zoology, geology, paleontology, meteorology, magnetism, physics, physiology, philology, and many other subjects. The several series comprise (1) The Annual Report of the Board of Regents to Congress with a general appendix of papers illustrating progress in a wide range of scientific branches; (2) Smithsonian Contributions to Knowledge, begun in 1850, in quarto form; (3) Smithsonian Miscellaneous Collections, in octavo; (4) Harriman Alaska Series, on the results of the scientific expedition to Alaska in 1899; (5) Bulletin of the National Museum, including Contributions from the United States National Herbarium; (6) Proceedings of the National Museum; (7) Annual Report of the National Museum; (8) Annual Report of the Bureau of American Ethnology; (9) Bulletin of the Bureau of American Ethnology; (10) Annals of the Astrophysical Observatory; and (11) a number of special publications independent of the above series.

There is also communicated to Congress through the Secretary of the Institution the annual report of the American Historical Association and of the National Society of the Daughters of the American Revolution.

The complete collection of Smithsonian publications numbers about 450 volumes, aggregating more than 200,000 printed pages.

Since it would be impossible through the limited funds of the Institution and printing allotments by Congress to meet the great popular demand for Smithsonian publications, they are necessarily almost entirely distributed to learned institutions and important public libraries, where they are available for general reference. Through this distribution there developed a system of exchange of Smithsonian publications with those of scientific and literary societies of the United States and of other parts of the world and a general interchange of publications of American and foreign institutions, which has come to be known as The Smithsonian International Exchange Service. In 1886 a treaty was made in Brussels between the United States and a number of foreign countries providing for the interchange of their governmental, scientific, and literary publications, and the work of carrying out its provisions in the United States was intrusted by Congress to the Smithsonian Institution.

Under certain regulations the Institution accepts from correspondents in this country publications intended as exchanges and donations, and they are shipped by freight, at intervals not exceeding a month, to about 60 distributing bureaus or agencies abroad, which in turn receive from correspondents in their countries and forward to the

Smithsonian Institution, under certain rules, publications addressed to institutions in the United States and territory subject to its jurisdiction. This service handles annually from 300,000 to 350,000 packages, weighing upward of half a million pounds. Through its operation the national collection of books in the Library of Congress has been greatly increased.

SMITHSONIAN LIBRARY.

The accumulation of a scientific library has been an important phase of the Institution's work in the "diffusion of knowledge," and the collection has increased in size from year to year, until at present it numbers well over half a million titles.

The main Smithsonian library is assembled in the Library of Congress, and is known as the Smithsonian deposit. This collection consists chiefly of transactions and memoirs of learned institutions and scientific societies and periodicals relating to science in general brought together from all parts of the world on a systematic plan since the middle of the last century. The National Museum and the library of the Bureau of American Ethnology also maintain large special libraries, and there are libraries connected with the Astrophysical Observatory and the National Zoological Park, besides some 35 specialized sectional collections located in various offices for the use of the scientific staff of the Institution and its branches. The Smithsonian office library contains a collection of books relating to art, the employees' library, and an extensive aeronautical library.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

The Smithsonian Institution directs the work of the United States Bureau of the International Catalogue of Scientific Literature, which is one of 33 regional bureaus in various countries engaged in the collecting, indexing, and classifying of scientific publications of the year. The classified references are forwarded to the central bureau in London, where they are collated and published in a series of 17 annual volumes covering each branch of science and aggregating about 8,000 printed pages. These volumes are sold at an annual subscription price of $85, chiefly to large reference libraries and important scientific institutions, the proceeds covering in part the cost of publication. From 1901 to 1916 the bureau at the Smithsonian Institution forwarded to London about 350,000 reference cards to publications issued in the United States during that period.

A plan for a work of this character was proposed as early as 1855, when Secretary Henry, of the Smithsonian Institution, called the attention of the British Association for the Advancement of Science to the great need of an international catalogue of scientific works.

In 1867 the Royal Society of London published its well-known "Catalogue of Scientific Papers," and the Smithsonian Institution has from time to time issued catalogues of the literature of special branches of science. In 1894 the Royal Society invited the Governments of the world to send delegates to a conference to be held in London in 1896. At this and the following conferences in 1898 and 1900 a plan was formulated to start the work with a classified subject and author catalogue of all original scientific literature, beginning with January 1, 1901.

THE UNITED STATES NATIONAL MUSEUM.

By the act of 1846 the Smithsonian Institution was made the custodian of the national collections in both nature and art. The Museum branch was definitely organized in 1850, the title "U. S. National Museum" being authoritatively given by Congress in 1875. During the first few years expenses of the Museum were wholly met from the Smithsonian fund, and it was not until 1878 that the Government began to provide entirely for its maintenance, this being done through annual appropriations by Congress.

The Museum staff includes the Secretary of the Institution as keeper ex-officio, the assistant secretary in immediate charge, the administrative assistant, three head curators, and about 50 curators, assistant curators, custodians, and aids, besides many clerks and other employees.

Four general divisions are recognized: (1) Natural history, including ethnology and archeology; (2) the fine arts; (3) the industrial arts; (4) history.

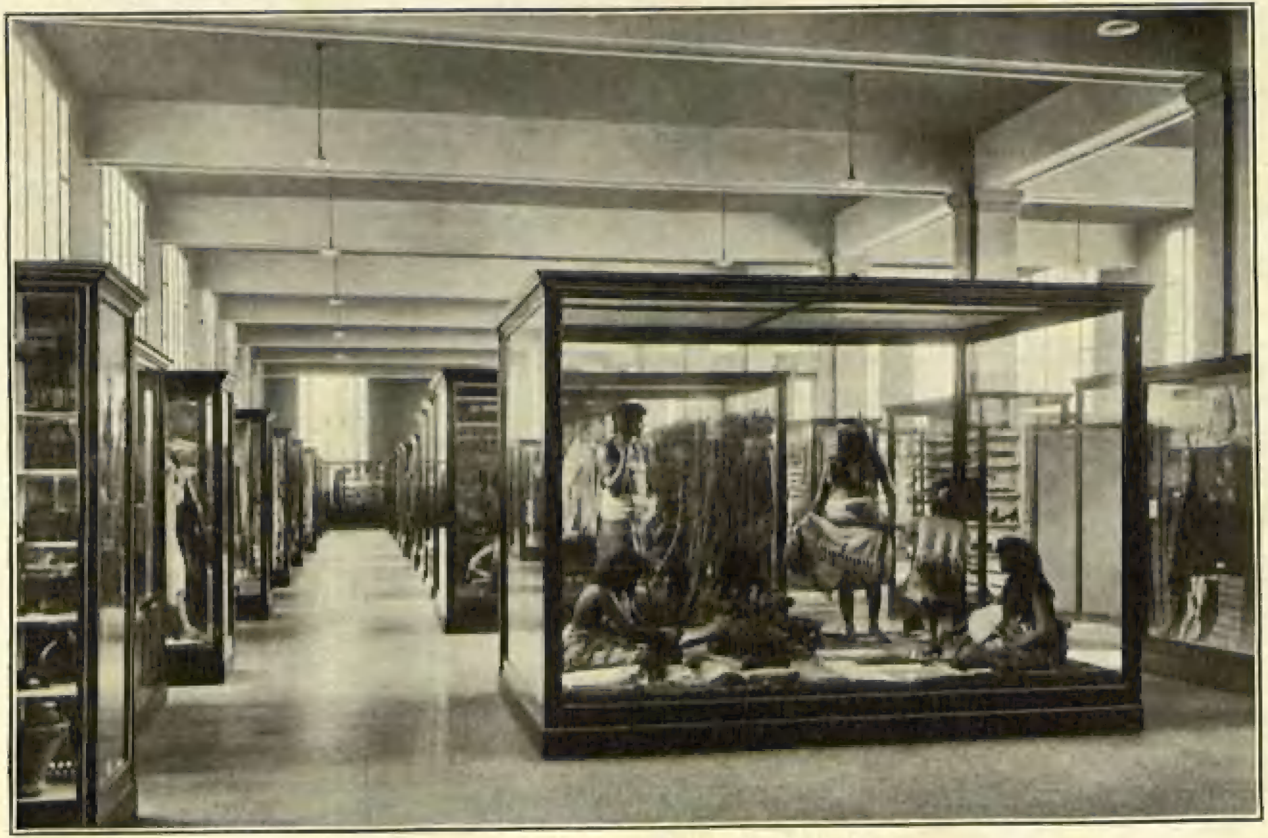
The division of natural history is divided into three departments, biology, geology, and anthropology. The collections of natural history have been received in greater part from Government surveys and explorations, and are richest in material from North America. Many other parts of the world are also well represented in one subject or another, especially Central America, the Philippines, Malaysia, and some portions of Europe, Africa, and South America. The deep-water zoological collections from both the Atlantic and Pacific Oceans are the most extensive and important in existence.

Among important early sources of collections may be mentioned the United States Exploring Expedition of 1838 to 1842, the Perry Expedition to Japan, the North Pacific Exploring Expedition of the Navy, the railroad and wagon-road surveys by the Army in connection with the opening up of the far West, the Canadian and Mexican boundary surveys, certain geological explorations, and the work of the coast survey in Alaskan waters, besides many expeditions organized or assisted by the Smithsonian Institution. Of more

EXHIBITION OF FOSSIL VERTEBRATES, U. S. NATIONAL MUSEUM.

EXHIBITION OF FOSSIL VERTEBRATES, U. S. NATIONAL MUSEUM.

GROUP OF AFRICAN LIONS FROM ROOSEVELT EXPEDITION, U. S. NATIONAL MUSEUM.



ETHNOLOGY EXHIBITS, U. S. NATIONAL MUSEUM.

recent date are the investigations of the Bureau of Fisheries, the Geological Survey, the Bureau of American Ethnology, and the Bureaus of Plant Industry, Entomology, and Biological Survey of the Department of Agriculture. Of private donors, some of whom have made gifts of great extent and value, the list is very long.

The total number of specimens in all branches of natural history recorded to the present time amounts to several millions, the annual accretion during several years past having averaged a quarter of a million specimens.

Of arts and industries there are on exhibition extensive collections of firearms, the most complete in this country; boat and railroad models, electrical apparatus, time-keeping and measuring devices, musical instruments, ceramics, graphic arts, textiles, laces, embroideries, and collections in mineral technology and in photography.

The growth of the National Museum has heretofore been greatest in natural history lines, including primitive man. The development of the natural resources of the country and the study of the American aborigines through Government surveys and explorations have contributed toward building up collections illustrative of nature and early man that equal if not actually surpass those of any other country. The millions of specimens and hundreds of thousands of distinct species and forms here preserved serve as the basis for extended researches and discoveries. Through cooperation with the executive departments of the Government the Museum collections constantly render aid in solving many broad economic problems in agriculture, in mining, in fisheries, and in Indian affairs. Unrivaled conditions are here afforded for the arrangement, care, and safety of the Nation's treasures, for their unrestricted study in the advancement of knowledge, and for their use in promoting the interests of public education.

In recent years great advance has been made in the development of the department of technology—a Museum of Industrial Arts. It is in this department in particular that the Museum manifests one of its principal functions. The exhibits are so selected and so installed as to teach visitors how things are made and what they are made of, and not so much who makes the best articles or how they should be packed to meet the demands of trade. And yet while these collections first of all educate the public they also teach the manufacturer and therefore are of decided economic importance. While commercial museums have their place for developing trade and commerce, and are of much value for such purpose, the development of the artistic taste of the public through an educational Museum of Industrial Arts seems of even greater general importance. It stimulates inventive skill and advances every art and every

industry. The exhibits illustrating textile industry and mineral technology in particular are very complete, consisting of specimens of raw materials, machinery used in manufacture, and the finished products.

The division of history has likewise greatly broadened in recent years. Here are displayed memorials of many leading American soldiers and sailors, inventors, explorers, and men of science, and memorials of important events in American history. A collection of costumes worn by ladies of the White House during each administration since 1789 is of much popular interest. Among other objects of historic value are large collections of postage stamps, coins, and medals.

The Museum has been defined as one of record, of research, and of education. As a Museum of record it preserves the very foundations of an enormous amount of scientific knowledge in the many thousands of type specimens from numerous natural-history investigations, and these are increasing rapidly as the results of new researches and explorations are here permanently deposited. As a Museum of research the collections serve as a stimulus to inquiry and the foundation for further investigation. The installation of exhibits is carefully planned to make the Museum an aid to public education. Every kind of natural object and every manifestation of human thought and activity are illustrated by specimens accompanied by general and descriptive labels. Races of men are illustrated by groups of figures in their native costumes, many of them represented in their daily occupations; mammals, birds, and other zoological specimens are each assembled in groups with natural surroundings. In every exhibition hall the educational feature is constantly kept in mind.

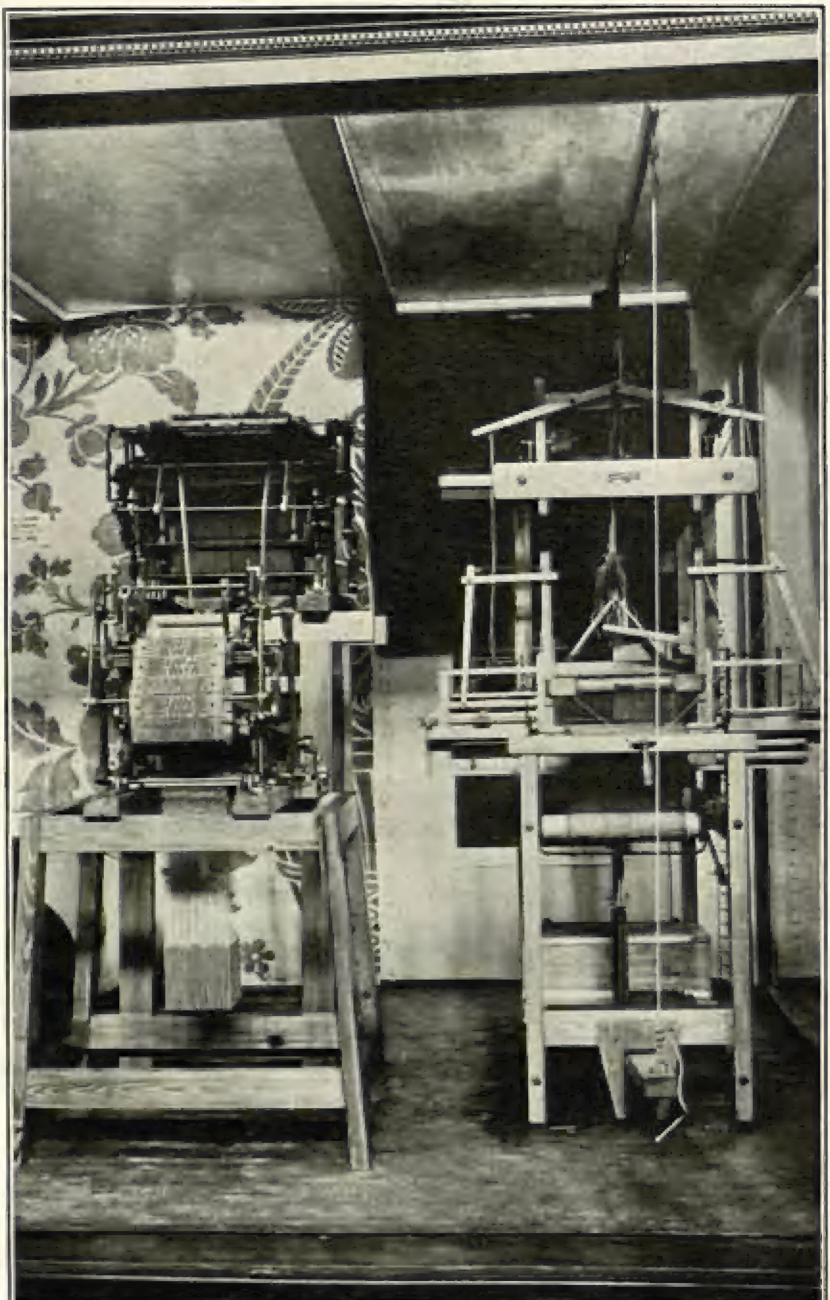
It is "a consultative library of objects," an agency for the instruction of all the people of the country, "and it keeps in mind the needs of those whose lives are not occupied in the study of science as well as those of the professional investigator and teacher."

THE NATIONAL GALLERY OF ART.

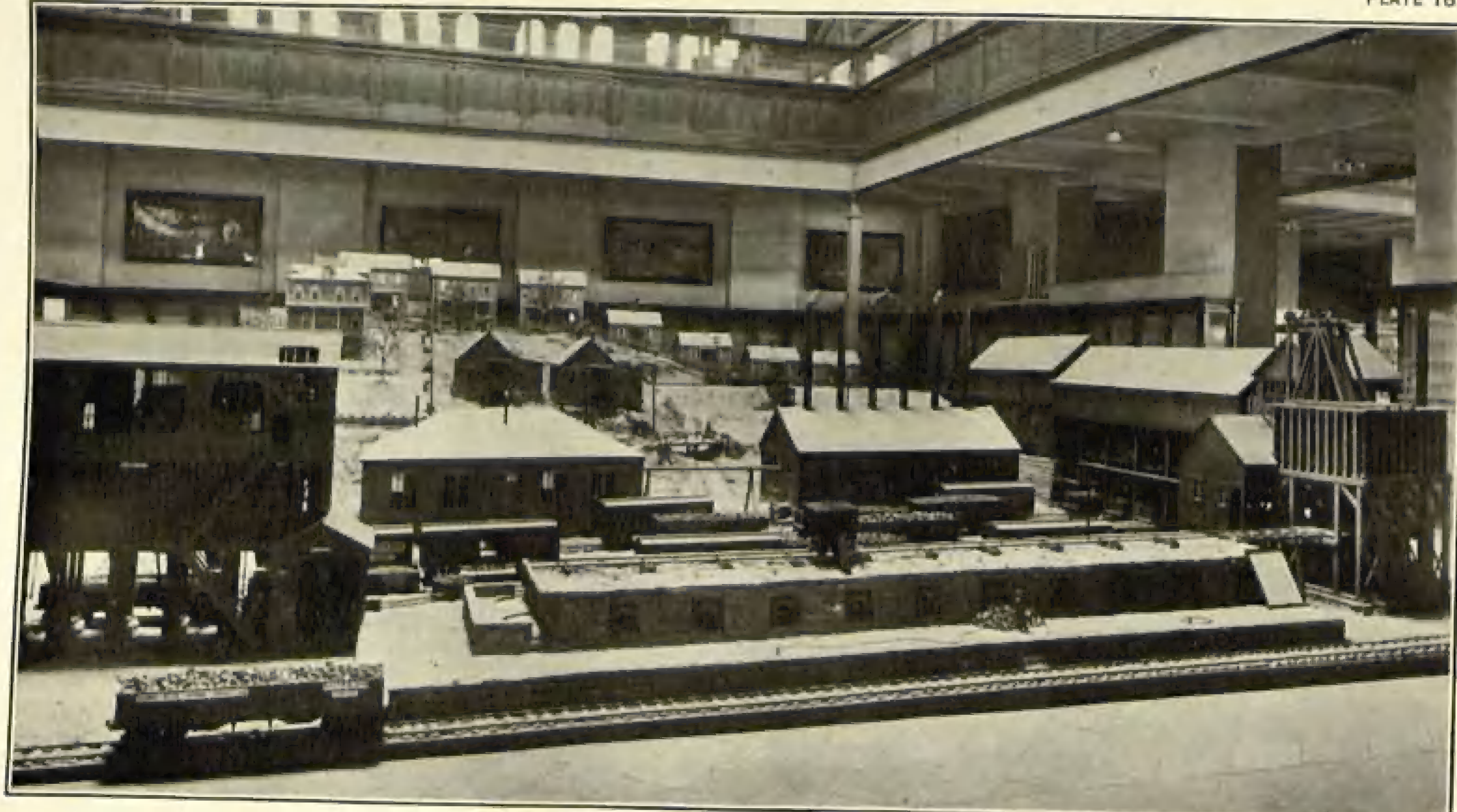
The foundation of a National Gallery of Art was contemplated and directed in the act of organization of the Institution in 1846 and in the program of operation adopted by the Board of Regents in 1847. It was several years, however, before the gallery was in active operation. The national gallery received very great stimulus in 1906 through the bequest of Harriet Lane Johnston, niece of President Buchanan; the munificent gift of Mr. Charles L. Freer, and the gift of Mr. William T. Evans, thus bringing into national ownership a very rich collection of paintings and other objects of

EXHIBITION GROUP OF CHILKAT INDIANS, U. S. NATIONAL MUSEUM.

EXHIBITION GROUP OF BERING STRAIT ESKIMO, U. S. NATIONAL MUSEUM.



JACQUARD MACHINES, U. S. NATIONAL MUSEUM.



WORKING MODEL OF COAL MINE, U. S. NATIONAL MUSEUM.

art. The gallery is now administered as the department of fine arts of the National Museum.

The collections of the gallery include (*a*) paintings and other objects which had long been in the custody of the Institution; (*b*) the Harriet Lane Johnston bequest, including a number of highly interesting and valuable paintings and sculptures; (*c*) the William T. Evans gift of more than 150 carefully selected works by modern American painters; (*d*) the Charles L. Freer collection, numbering more than 5,000 items of paintings, sculptures, pottery, bronzes, jades, and other works of art; (*e*) a collection of 82 drawings in pencil, pen, charcoal, chalk, crayon, and water color executed by eminent contemporary French artists.

The munificent donation by Mr. Freer of his collection and provision for its preservation is unsurpassed in this country and is one of the most notable gifts of its character in the world's history. Mr. Freer describes his collection as follows:

> These several collections include specimens of very widely separated periods of artistic development, beginning before the birth of Christ and ending to-day. No attempt has been made to secure specimens from unsympathetic sources, my collecting having been confined to American and Asiatic schools. My great desire has been to unite modern work with masterpieces of certain periods of high civilization harmonious in spiritual and physical suggestion, having the power to broaden esthetic culture and the grace to elevate the human mind.

The original collection consisted of about 2,300 paintings and other objects of art and has since been increased to 5,346 items, including American paintings and sculptures, the Whistler collection, and oriental paintings, pottery, bronzes, and jades from China, Korea, Japan, and other Asiatic countries.

Mr. Freer retains his collection in his home city until the completion of the building now under construction in the Smithsonian Park, for which he has placed in the hands of the Institution the sum of $1,000,000.

BUREAU OF AMERICAN ETHNOLOGY.

The Bureau of American Ethnology is an outgrowth of early ethnological and archeological researches of the Institution, and of later investigations conducted in behalf of the Commissioner of Indian Affairs to determine the affinities of the various tribes of Indians to serve as a guide in grouping them on reservations, as it was believed that an effective classification of the tribes materially reduced the danger of warlike outbreaks. A vast amount of linguistic and bibliographical information relative to the American Indians has been published by the Bureau, and great collections of

ethnological material have been gathered for the anthropological department of the Museum.

Several years ago there was begun a series of handbooks on the American Indians. The first of these, in two volumes, was the Handbook of American Indians North of Mexico, containing a descriptive list of the stocks, confederacies, tribes, tribal divisions, and settlements, with sketches of their history, archeology, manners, arts, customs, and institutions. The second series, Handbook of American Indian Languages, discusses the characteristics and classification of the 55 linguistic families north of Mexico and their relation to ethnology. Further series, including a Handbook of American Antiquities, a Handbook of Aboriginal Remains East of the Mississippi, and handbooks of the Indians of the several States, are in preparation. Since 1879 the Bureau has published 34 volumes of annual reports and 62 bulletins, covering every phase of American Indian life and history. It has surveyed, excavated, and put in condition for permanent preservation a number of aboriginal ruins in the southwestern portion of the country, and is constantly cooperating with the Department of the Interior and with archeological societies in the work of saving these interesting sites for the benefit of future generations. Field operations by the Bureau during recent years in New Mexico, Arizona, Colorado, and Wyoming have brought to light exceedingly interesting aboriginal remains that have been set apart as national monuments.

NATIONAL ZOOLOGICAL PARK.

In 1890 the Congress set apart 167 acres in the beautiful Rock Creek Valley on the northwestern borders of Washington City as the National Zoological Park, which was founded "for the advancement of science and the instruction and recreation of the people," and Congress placed its administration in the Board of Regents of the Smithsonian Institution. The collection of mammals, birds, and reptiles numbers about 1,400 individuals, representing some 360 species. Its visitors now average about 1,000,000 each year, including many groups of public and private school students accompanied by their teachers.

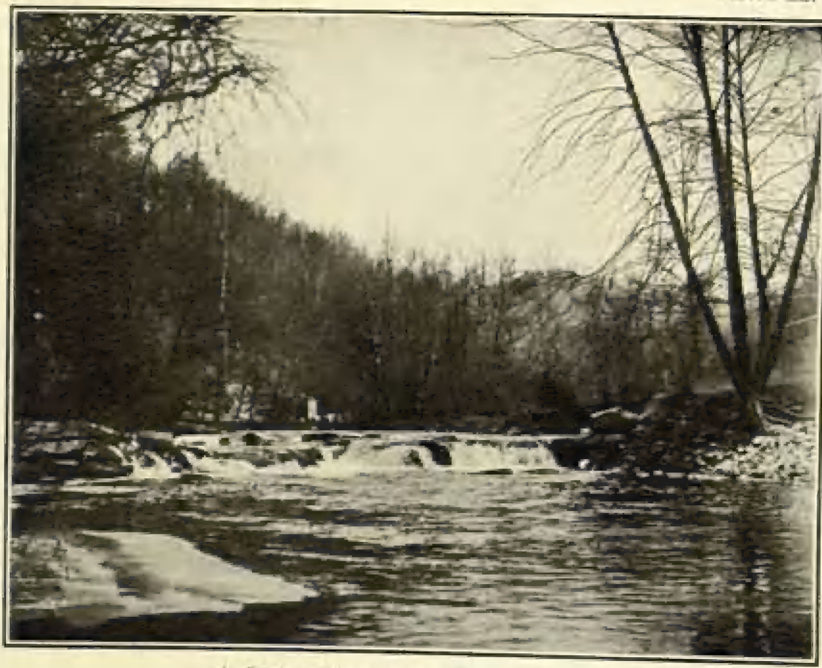
Among the buildings in the park are the lion house, containing the large cats and other animals, the monkey house, the bird house, houses of the elephants, and the antelope house. There are also inclosures for bears, pumas, wolves, and foxes; pools for sea lions and other water-loving animals, and paddocks for deer, lama, yak, and other ruminants; also many cages for small animals. Wild turkeys, partridges, peacocks, squirrels, and wild rabbits wander in perfect freedom throughout the park.

MAMMAL HOUSE, NATIONAL ZOOLOGICAL PARK.

VIEW IN NATIONAL ZOOLOGICAL PARK.

1. FLIGHT CAGE, NATIONAL ZOOLOGICAL PARK.

2. SWAN IN NATIONAL ZOOLOGICAL PARK.



1. FORD IN NATIONAL ZOOLOGICAL PARK.

2. POLAR BEAR CAGE, NATIONAL ZOOLOGICAL PARK.

One of the principal aims in establishing the park was to promote the preservation of races of animals threatened with extinction, such as the American bison, which once roamed in vast herds over the western plains and was rapidly disappearing before the advance of railroads and the rapacity of hunters. Several bison were secured for the park and have thrived here, and through the efforts of the Smithsonian Institution and others the Government was aroused to establish preserves in the West where the bison breeds freely.

There are several large cages for birds in the park. The great "flight cage," 158 feet long by 50 feet in width and height, is built over several full-grown trees and has a running stream of water supplying pools for the convenience of the birds, which are mainly herons, stolks, cranes, cormorants, gulls, and pelicans.

Among the particularly important exhibits is a fine collection of ungulates, or hoofed animals, no less than 50 species of wild cattle, deer, sheep, goats, antelopes, horses, and their kindred being represented, many of them by breeding herds. There is also a valuable collection of North American water fowl, a specially prepared breeding lake being set aside for the wild ducks, geese, and swans of this continent.

ASTROPHYSICAL OBSERVATORY.

The Astrophysical Observatory, founded in 1890, investigates solar radiation, and in general, solar phenomena, and has produced a complete chart, made by automatic processes, which shows in detail the so-called invisible spectrum. The work of this Observatory is especially directed to those portions of the energy of the sun that affect through its radiation the climate and the crops.

Through the use of specially designed pyrheliometers attached to free balloons, observations have been made of the intensity of solar radiation at various elevations up to a height of more than 80,000 feet above sea level. Special studies have been made of the solar constant and of the distribution of radiation over the sun's disk. The principal astrophysical work is carried on at the observatory in the Smithsonian Park in Washington and at Mount Wilson and Mount Whitney in California. On the summit of Mount Whitney the Institution has constructed a shelter for the general use of observers. Expeditions to various parts of the world have been made for observation of eclipses of the sun and other special studies.

As the result of researches made by the observatory during the period from 1900 to 1915 it is found that the average value of heat emitted by the sun is 1.932 calories per minute per square centimeter, and that the heat emitted in a year equals that obtained by

burning four hundred sextillion (400,000,000,000,000,000,000,000) tons of anthracite coal. It is found that there is a variability in the sun's radiation, with a range about 7 per cent irregularly in periods of a week to 10 days. The sun's radiation is generally greater, particularly toward the center of the solar disk, at sun-spot maximum, though the temperature of the earth is generally greater at sun-spot minimum. Standard pyrheliometers have been recently devised by the Astrophysical Observatory for measuring solar heat and are in use at observatories in several parts of the world, and also a pyranometer for measuring the intensity of skylight by day and radiation outward toward the sky at night. These studies are of economic agricultural importance as well as of scientific interest.

ORIGIN OF THE INSTITUTION.

James Smithson, of England, a graduate of Oxford University, Master of Arts, Fellow of the Royal Society, a chemist and mineralogist, made his will in 1826 bequeathing his property to the United States of America to found the Smithsonian Institution at Washington for the increase and diffusion of knowledge among men. He died in Italy in 1829. In July, 1835, the Secretary of State was officially informed of the bequest, and on December 27, President Andrew Jackson communicated the papers to Congress. The message of the President was referred to the Senate Committee on the Judiciary and to a select committee of the House of Representatives. After deliberate discussion of the authority and propriety of the United States Government to accept such a trust for the purpose stated, there was approved by the President, on July 1, 1836, an act of Congress to authorize and enable the President to assert and prosecute with effect the claim of the United States to the Smithson legacy, and Mr. Richard Rush was appointed agent of the United States for that purpose.

On December 3, 1838, the Secretary of the Treasury reported to the President that the bequest, amounting to $508,318.46, had been paid into the Treasury of the United States.

In a message to Congress on December 6, 1838, President Van Buren invited attention to the obligation devolving upon the United States to fulfill the object of the Smithson bequest. For eight years thereafter the subject was under consideration in the Senate and House, resulting in the founding of the Institution by an act of Congress of August 10, 1846, and by law the Smithsonian fund was made perpetually entitled to an annual income of 6 per cent interest, and definite resources were thus assured for carrying out the purposes and objects of the founder of the trust. Since the original bequest by Smithson, other bequests and gifts have come to the Institution

from generous benefactors, varying in amounts from a quarter of a million to the modest, but none the less acceptable, sums of a thousand dollars or less, until the total invested permanent fund now aggregates more than a million dollars, and is gradually increasing from year to year.

In discussing the acceptance of the Smithson bequest in 1836, John Quincy Adams, in the House of Representatives, said:

> Of all the foundations of establishments for pious or charitable uses, which ever signalized the spirit of the age, or the comprehensive beneficence of the founder, none can be named more deserving of the approbation of mankind than this. Should it be faithfully carried into effect, with an earnestness and sagacity of application, and a steady perseverance of pursuit, proportioned to the means furnished by the will of the founder and to the greatness and simplicity of his design as by himself declared "the increase and diffusion of knowledge among men," it is no extravagance of anticipation to declare that his name will be hereafter enrolled among the eminent benefactors of mankind.

Eighty years have passed since Mr. Adams spoke those prophetic words. The name of James Smithson, and the Smithsonian Institution, which he founded, are to-day known to all men of science, and everywhere are held in the highest esteem.

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NEWS FROM THE STARS.

By C. G. Abbot,

Director, Astrophysical Observatory, Smithsonian Institution.

[With 5 plates.]

Light is the messenger that brings the news. The message is in cipher, very long, faint, and hard to read. It tells of the materials, classification, temperatures, motions, distance, grouping, brightness, variability, mass, size, and number of the stars.

MATERIALS.

Starlight collected by a telescope is passed through a spectroscope. This forms a narrow band, called the spectrum, violet at one end, red at the other. A photograph of the spectrum is made, and for most stars this shows the band of colors crossed by dark lines.

Suppose an electric arc is made to play between iron poles, and its light is sent through the spectroscope. Instead of a bright continuous spectrum with *dark* lines, as given by a star, there appears its exact opposite—a very faint spectrum crossed by *bright* lines, especially numerous where the green occurs in the spectrum of starlight.

Matched together, one spectrum above the other, the bright iron lines occur where the dark lines cross the star spectrum. So unmistakably is one the reversal of the other that the coincidence seems to give proof of the presence of iron in the star. Probability becomes assurance when it is known that under some circumstances iron vapor can produce *dark* lines on bright spectrum ground, just as usually found in starlight, and that some stars, on the other hand, show *bright* lines on a faint spectrum background.

Hydrogen, helium, oxygen, calcium, and many other elements are similarly shown to exist in the stars by spectroscopic examination of starlight. But not all the stars show all these elements. Great differences are found in the stellar spectra, and stars are classified accordingly.

CLASSIFICATION.

As proposed at Harvard College Observatory, the following classification of stellar spectra has been generally adopted: Class O (Wolf-Rayet type). The spectrum consists of *bright* lines on a faint continuous background. Class B (Orion type). Dark lines of helium are sparsely set on a bright ground. Class A (Sirian type). Hydrogen lines are most conspicuous. Class F (calcium type). Hydrogen lines are still conspicuous, but many lines of metals appear faintly, and notably two great lines of calcium in the violet. Class G (solar type). Numerous strong metallic lines occur as in sunlight. Class K (sun-spot type). The lines are darker and sun-spot flutings occur. Hydrogen lines are faint. Type M (fluted type). Titanium oxide flutings are strong, and carbon flutings also well marked. Several other classes are noted by specialists, but those above named are the chief ones (pl. 1).

The classification of the stellar spectra is a very important aid to research. It is found that motions, position in the heavens with reference to the Milky Way, size, temperature, distance, and other characteristics of stars, vary with spectral class. Director Pickering, of Harvard College Observatory, has already done a work of high value in securing the spectra and publishing the classification of about 6,000 stars covering both the northern and southern hemispheres. Now a new publication is about to be made by Harvard College Observatory, giving the classification of the spectra of above 200,000 stars, all observed by the Harvard staff, and all examined by Miss A. J. Cannon within the last four years.

TEMPERATURES.

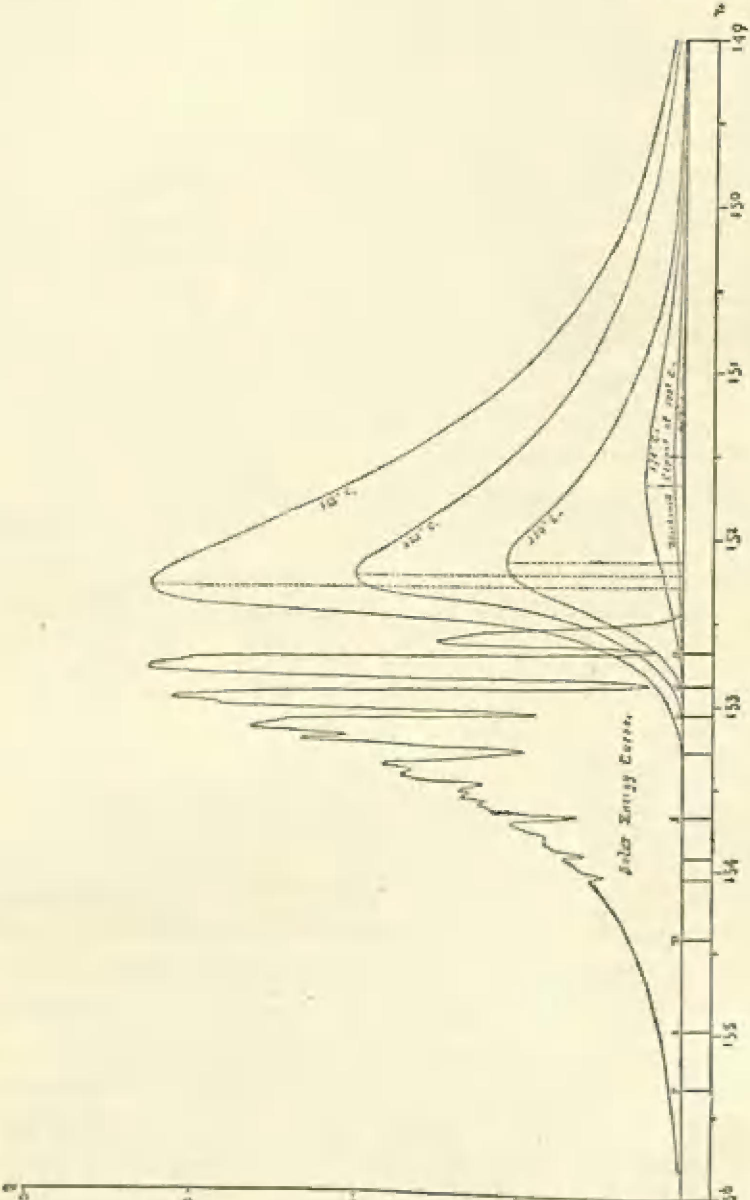
Cold iron does not shine in the dark, but let the smith heat it in his forge and soon it glows red, then yellow, then white hot. The hotter the body is the more its spectrum is enriched toward the violet end as compared with the red. Exact mathematical relations are known to connect temperature and distribution of light in the spectrum. Working on this basis, it is found that our sun's surface appears to be at about 6,000° centigrade (10,800° Fahrenheit) above the melting temperature of ice. (See pl. 2.)

By photographic methods Wilsing and Scheiner, of the Astrophysical Observatory at Potsdam, in Germany, have assigned temperatures to about 100 of the brighter stars. The results run from 9,000° C. for class B down to 3,000° C. for class M, varying in fairly regular progression.

Very recently Coblentz, of the National Bureau of Standards, working temporarily at Lick Observatory in California, has succeeded in measuring the heat caused by the rays of stars so faint that

CLASSIFICATION OF STELLAR SPECTRA (ADAMS).

From Harper's Magazine, October, 1916.



PRISMATIC SPECTRUM (LANGLEY).

From Proc. Amer. Asso. Adv. Sci., Vol. 34, 1885.

the eye can scarcely see them. For this purpose the rays were collected by a concave mirror of 3 feet diameter and focused on the surface of a very delicate electrical thermopile (pl. 3 and pl. 4, fig. 2). This instrument acts on the principle that a difference of temperature between the junctions of two metals made up into a closed wire circuit, produces an electric current. The apparatus used was so delicate that if the experiment could be made in a vacuum the heat from rays of a candle at 53 miles could be observed. Further work along similar lines is proposed.

DISTANCE.

When a surveyor measures the distance of an inaccessible object he selects two convenient stations and measures their distance apart. This is called the base line. At each end of the base line he observes the angle the base line makes with a line sighted toward the inaccessible object. The angles and the base of his triangle being thus measured, the two remaining sides can be calculated. By such a process, using the earth's diameter, or a large part of it, as the base line, the distance of the moon is readily determined, and comes out 243,000 miles.

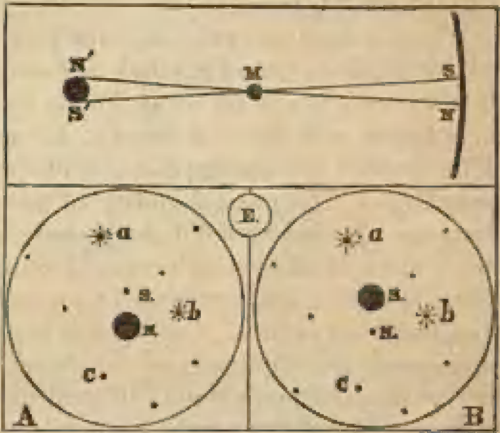


FIG. 1.—Method of triangulating for distances of heavenly bodies. From "The Sun," by C. G. Abbot. Published by Appleton & Co., 1911.

Even the length of a diameter of the earth is too small a base line from which to triangulate for the distances of the stars. Astronomers use the diameter of the earth's orbit round the sun, 186,000,000 miles, for this. Astronomers also take advantage of the fact that very faint stars are usually much farther away (though not invariably so) than bright ones. Thus it comes about that if photographs of a bright star are made with the same telescope at two dates six months apart, and exact measurements of the distance of the bright star from its faint neighbors are made on both photographs, a slight displacement of the bright star will often be found to have occurred. The angular measure of displacement gives the vertical angle of the isosceles triangle of which the base line is the diameter of the earth's orbit, and from these data the star's distance is easily found. Seen from the nearest star, α Centauri, the radius of the earth's

orbit, 93,000,000 miles, subtends an angle of only 0.75 seconds. This is called the star's parallax.

Up until very recently the parallax determinations of Elkin and Chase at Yale University Observatory, by direct eye observations with the heliometer, were regarded as of the highest accuracy. But now the photographic method as worked out at Yerkes Observatory by Prof. Schlesinger, now director at Allegheny Observatory, has come to be preferred. This work is being pushed by Director Mitchell, of Leander McCormick Observatory, and is also occupying a prominent place on the program at several other observatories where large telescopes are available.

Altogether less than 1,000 star distances have been measured. It is a slow, tedious work, often disappointing. α Centauri, the nearest star, except the sun, is at 25,000,000,000,000 miles, while the sun is at only 93,000,000 miles.

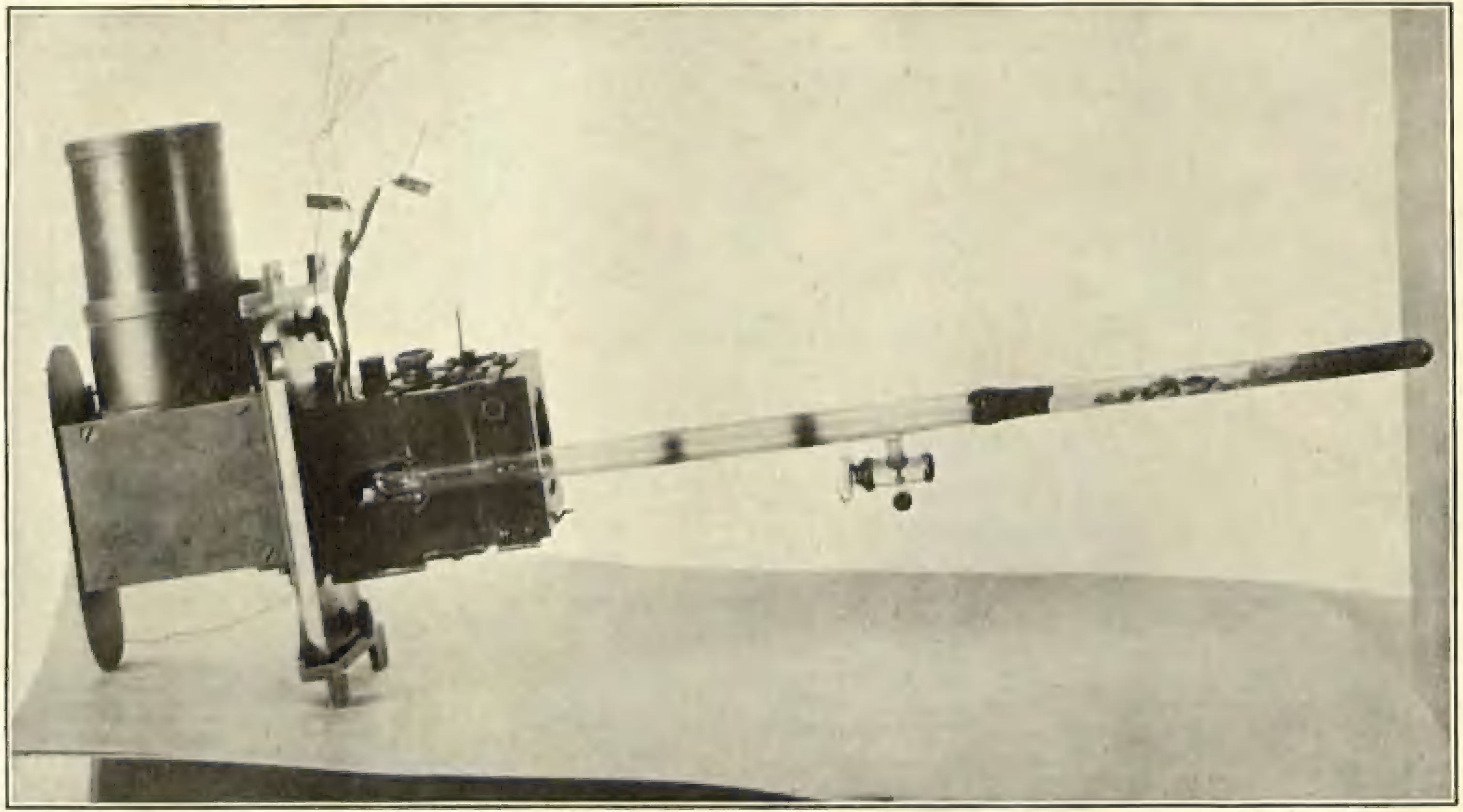
When a measurement indicates that a star is at 2,000,000,000,-000,000 miles or more (parallax 0.01 seconds) it is the same as saying that the star is too far away for its distance to be determined. It may be ten or a hundred times as far as the measurements indicate. This is about the average distance of the faintest stars visible to the naked eye. The great majority of telescopic stars lie beyond this distance. If observers did not choose stars expected to be relatively near, most of their results would come out thus indeterminately. Even as it is, a great number of measurements do come out in this disappointing fashion. Unless some better method of investigation is discovered, measurements of individual star distances must ever be in this unsatisfactory state. In treating of star motions we shall see how our knowledge of the average distances of certain groups of stars has been extended.[1]

MOTIONS.

About the year 1750 the English astronomer royal, Bradley, observed the positions in the heavens of 3,222 stars. Bradley's stars and many others have been observed often in more recent years. All the best work relating to about 6,000 of the brighter stars was compared and reduced to a homogeneous system about the year 1910 by the late Prof. Lewis Boss, of the Dudley Observatory and Carnegie Institution.

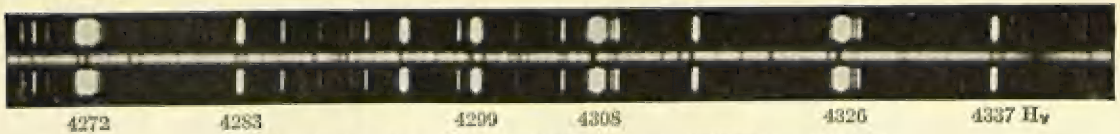
From Boss's work the proper motions (so called) of these stars were accurately determined. All stars, including our sun, move

[1] Since this paragraph was written Dr. Adams, of Mount Wilson Solar Observatory, has discovered a spectroscopic method of determining parallaxes, which is applicable to stars of classes F, G, K, and M, and is independent in accuracy of the distance of the star, if it is sufficiently bright to permit a good spectrum photograph to be made.

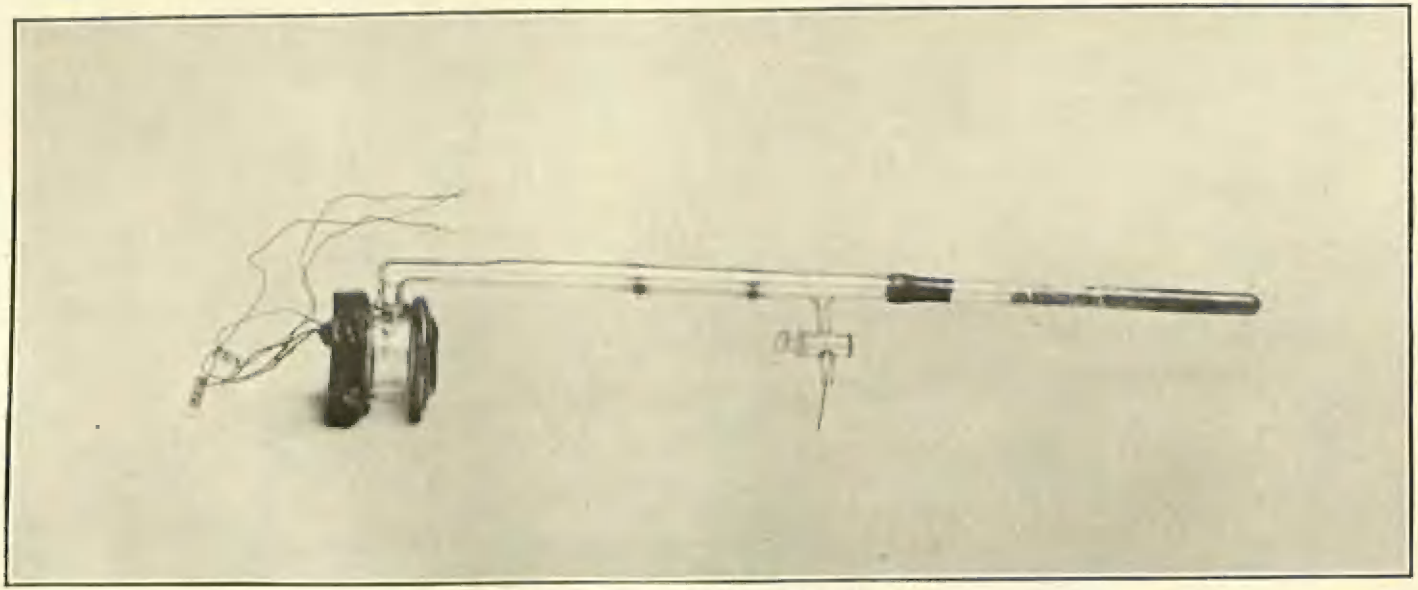


COBLENTZ STELLAR THERMOPILE MOUNTED.

From Bulletin of U. S. Bureau of Standards, Vol. 11.



1. SPECTRUM OF PROCYON WITH IRON COMPARISON SPECTRA. (ADAMS.)
From "The Sun," by C. G. Abbot. Published by Appleton & Co., 1911.



2. COBLENTZ STELLAR THERMOPILE, DETAIL.
From Bulletin of U. S. Bureau of Standards, Vol. 11.

each with his own rate and direction, so that at the end of a century the configuration of the heavens is not quite the same as at its beginning. These "proper motions" range from 870 seconds of arc per century down. (A second of arc is about the angular width of a telegraph wire as seen at a distance of a half mile.) The vast majority of stars have a less proper motion than 20 seconds per century.

Proper motions are observed as angles and can not be expressed in miles per second without other information. We see only the component of motion at right angles to the line from the earth to the star. If a star is coming directly toward us, it has no proper motion, though its real speed may be very great. Near stars have greater average proper motions than distant ones, just as men walking on the other side of the street apparently outdistance those a block away. Two things besides proper motion are therefore needed to determine the real motion of a star, namely, its distance and the angle its real motion makes to the line of sight.

Fortunately, the spectroscope can help in this matter. Although, as stated above, the chemical elements are discovered in stars by the reversal of their spectrum lines, careful measurement shows that the positions of the stellar lines are slightly shifted, either toward the red or toward the violet, with respect to the bright lines of the comparison spectrum of a metal. Doppler predicted this effect nearly a half century before it was observed in starlight. It depends on the motion of the star in the line of sight.

Light travels by waves. Violet light has more waves per second than red. If a star is approaching, its light seems to have more waves per second because the star's motion is added to that of light, and hence all the spectrum lines are shifted toward the violet. The lines are shifted toward the red for stars that are receding. From the amount of the shift the actual rate of approach or recession of the star may be found. Naturally, a small correction must be made for the motion of the earth on its axis and its motion round the sun. We then have the actual rate of motion of the star to or from the sun. It is a very valuable thing about this kind of measurement that if only a star is bright enough it makes no difference at all in the accuracy of the determination how distant the star may be. This unfortunately is not so with proper motions.

As the sun has a motion of its own, which Sir William Herschel rightly concluded in the year 1783 is toward the northern constellation Hercules and not far from the bright star Vega, all the stellar motions, of course, appear to be affected by an equal motion to that of the sun but in the opposite direction.

Director Campbell, of Lick Observatory, has recently published a collection of the so-called "radial motions" of nearly 2,000 stars,

resulting from his campaign of spectroscopic observing in both the Northern and Southern Hemispheres, begun about the year 1898. From this work he finds the sun to be moving at about 19.5 kilometers (12 miles) per second in its course among the stars.

Rapid progress is being made in measuring the radial motions of the fainter stars at Mount Wilson Solar Observatory. The 60-inch reflecting telescope there has been employed, under the direction of Dr. W. S. Adams, for this purpose since 1910, and the new 100-inch reflecting telescope also will soon be available. Other great reflectors are being prepared for Canada and for Argentina, and will doubtless be joined in this work. As it is a slow business at best, observers of the radial motions of the fainter stars will generally confine their measurements to what are termed Kapteyn's selected areas.

Prof. Kapteyn, of Groningen, Holland (who has just been decorated for his astronomical work by the Emperor of Germany with the Prussian order Pour le Mérite, at the same time with a group of generals, marshals, and kings), has been engaged for many years in a general study of the motions and distances of the stars. His studies are continually thwarted by lack of information about the fainter stars, which are so numerous that they will never be all observed individually. Hence Kapteyn has proposed that attention be devoted to 206 selected areas all over the sky, each about 1¼ degrees square, so that samples of the stars so chosen may have their positions, motions, brightness, distances, and spectral classes determined within a reasonable time. The distances will always be the weak point, but progress will be rapid along the other lines.

Now, let us see how knowledge of proper motions, radial motions, and distances can be combined when all three are known, as in the case of a few individual stars. From the distance and proper motion together we learn that the star appears to move at right angles to the line of sight at a certain rate in miles per second. The proper motion also indicates in which direction this cross motion is taking the star. The spectroscope indicates that the star is approaching or receding at a certain rate. By combining the two components—the apparent cross and radial motions—the actual speed and direction of the star's motion becomes fully determined. Applying next a correction for the known motion of the solar system, the star's own peculiar motion with respect to the whole system of stars is at length found.

STAR GROUPING.

As the distance is so weak a link in this chain, several devices have been employed to strengthen it, and these depend in one way or another on star grouping. First of all, there are a good many pairs of stars which have been shown by telescopic observations to be

THE PLEIADES. (G. W. RITCHEY.)

Photographed with the 2-foot reflector of the Yerkes Observatory, 1901, October 19. Exposure 3½ hours. Cramer Crown plate. From "The Sun," by C. G. Abbot. Published by Appleton & Co., 1911.

revolving about their common center of gravity. Spectroscopic determinations of radial motion for such telescopic double stars give sufficient additional information to yield us their distances.

Secondly, there are a number of large groups of stars, each of which have been found to have their peculiar motions all toward a single converging point. If the reader will stand at one end of a long corridor and look down the four corners of it as they stretch away from him, or, still better, will look from the back of a train at a long, straight stretch of railway, he will see at once that this convergence really means for these stars that their motions are all parallel. This could only happen if the stars were all of a single flock, moved by some common cause in the same direction. Finally, as these stars have been moving since a time *immeasurably* long ago, they would not now have been seen in the same part of the sky if their speeds were unequal. Such a group, therefore, consists of stars moving at equal speeds in parallel paths.

Yet their proper motions are unequal. This is because their distances are unequal. If now the distance of a single one of these stars can be determined in some way, the distance of every one of them whose proper motion is known follows at once.

But the great extension of knowledge as to star distances comes when stars are classified according to proper motion. Consider a large number of stars of equal proper motion. It is to be supposed that generally (apart from special groups like those just mentioned) their real motions will be at random in space, and though some will be moving squarely across the line of sight and showing all of their real motion, others moving nearly along the line of sight showing but little of it, the average of all proper motions will be approximately two-thirds of the average real motion. The same is of course true for large groups at two, four, or any number of times smaller average proper motion than the group first considered. Their average real motions will also be approximately 3/2 their average proper motions.

It is further to be supposed that the average of all the real motions in each of these large groups of stars is the same, whatever their distance from us. We may at least adopt this hypothesis for lack of knowledge to the contrary. If so, it follows at once that a large group of stars whose mean proper motion is one second is twice as far away on the whole as a large group of stars whose mean proper motion is two seconds.

Prof. Kapteyn has carefully compared all the known distances of individual stars with their proper motions, and has considered also in this comparison certain other data, especially brightness. In this way he has worked out a formula by which one can determine the average distances of stars of different mean proper motions, and thus

we escape from the limitations imposed by the comparative meagerness of our knowledge of individual stellar distances. According to Kapteyn's formulæ, the vast majority of the stars are so far away that it takes light thousands of years to come to the earth from them, though light travels 186,000 miles per second.

Returning now for a moment to the consideration of star motions, we understand at once that, just as the mean proper motion of a large group of stars corresponds to two-thirds of the average real motion of these stars, so the mean radial motion of the group is actually approximately two-thirds of the average real motion. Director Campbell has in this way worked out the average real motions of stars of different spectral classes, and Prof. Boss also has done the same, basing his result on the mean proper motions and mean probable distances. Their results are in very close agreement. Both find our sun to be moving a very little slower than the average of all stars in their lists.

When, however, the stellar motions are arranged by spectral classes they find the B stars moving slower, other classes faster and faster in a somewhat regular progression up to the M class stars. Quite recently Adams has extended this investigation to fainter stars. He finds these differences of speed between spectral classes not so great as found by Boss and Campbell, and the average speed of the fainter stars also less. It may be that the brighter stars, being relatively near us, form a special group, not quite representative of all the stars in the universe.

The greatest conception in regard to star grouping is that of "star streaming," recently worked out by Kapteyn and by Eddington, of the University of Cambridge, England. They find that when the proper motions of the stars are cleared of the effects of solar motion the remaining so-called "peculiar motions" of the individual stars, while they go to some extent at random, plainly indicate the governing influence of two great streams moving oppositely. If we could collect all the stars at one point and endow each of them with its "peculiar motion" just as it has been observed, then at the end of a century the stars would have stretched out, not into a sphere but into an ellipsoid, owing to the influence of the two star-streams. This grand phenomenon is attracting deep attention from astronomers to-day, and will undoubtedly play a great part in future studies.

BRIGHTNESS AND VARIABILITY.

Stars look hardly as bright as the fireflies of a summer night, but in reality they glow like the sun, and seem faint only because far away. Astronomers speak of "magnitudes" and of "absolute magnitudes." The first gives the relative brightness of the stars as

they seem to us to be, and the second as they would seem if all were equally distant. A difference of a magnitude means about 2½ fold in brightness, and five magnitudes 100 fold. Thus a star of sixth magnitude, which can just barely be seen by the naked eye, under best conditions, is 100 times fainter than stars of first magnitude, like Aldebaran, which is among the brightest. On this scale our sun is of —26.5 magnitude.

But on the scale of absolute magnitudes our sun is only an average star. If removed to Aldebaran's distance the sun would seem a fifth magnitude star. Some bright stars like Rigel, Canopus, and Deneb give thousands, perhaps hundreds of thousands or millions,

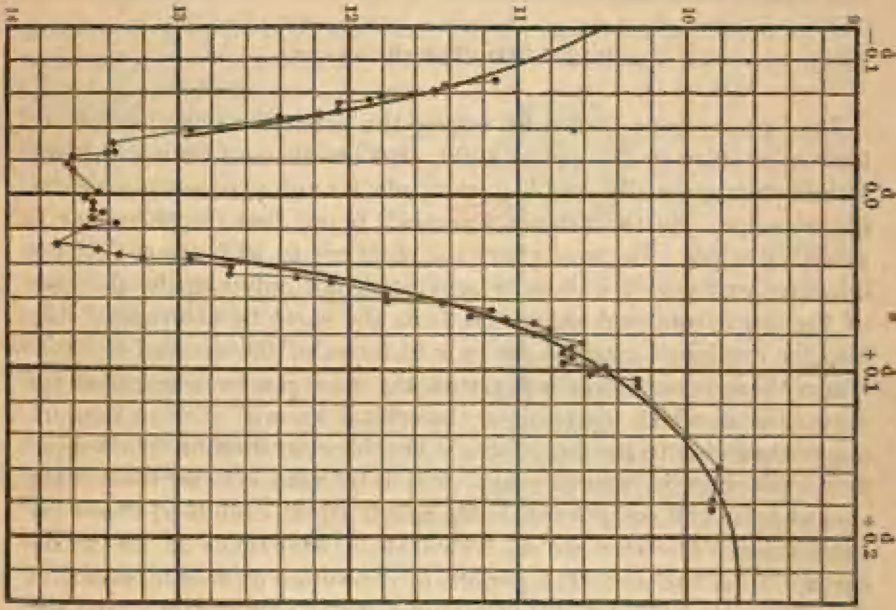


FIG. 2.—Light-curve of R R *Draconis* at eclipse (Sears). From Astrophysical Journal, vol. 36. Vertical scale, days; horizontal scale, magnitudes.

of times as much light as does the sun. On the other hand a vast number of stars give less light than the sun.

Measurement of brightness is called photometry. A very large program of stellar photometry has been done under Director Pickering at Harvard College Observatory. Many stars are found to be of variable brightness. It has been shown lately by the Smithsonian observers that even the sun is variable through a range of about 10 per cent. But most of the known variable stars vary much more widely than this. The cause of the variation is now known to be, in many but not all cases, the presence of a companion star so near the primary star as to be indistinguishable by the telescope, but discoverable by spec-

troscopic studies of motion in the line of sight. As the two stars revolve about their common center of gravity they alternately eclipse each other as seen from the earth. Of course the eclipse may be either total or partial, according to the relative sizes of the two stars and the inclination of their orbit to our line of sight. By a careful study of the variation of brightness of these objects it is possible to fix the period of revolution, the relative size of the two stars, the inclination of their orbit, and other data. This branch of astronomy has been much investigated at the Observatory of Princeton University under Director Russell, and a most interesting publication of the results has just been made by his pupil Shapley, now at Mount Wilson Solar Observatory.

MASS AND SIZE OF STARS.

The spectroscope shows, by noting the periodic variability of velocities of stars in the line of sight, that about one-fourth of all the visible stars are really double or multiple, though apparently single to the telescope. So, for instance, Campbell found that the polar star is probably triple. In cases where the stars are so wide apart that the telescope can perceive them as separated, not only can the distance of the stars from each other and from the earth be determined, but also the combined mass of the pair in terms of the mass of the sun. When there is no visible separation, the mass can be determined for some cases in which the plane of the orbit is known. For α Centauri, the nearest star to the sun, there is visible separation of two components, which revolve in 81 years. The total mass is twice that of the sun, and the two components being nearly equal, each is of about the sun's mass. The two are separated about 23.6 times as far as the earth is from the sun. The periods of revolution of double stars thus far determined spectroscopically range from 4½ hours to 90 years.

From the photometric study of eclipsing binary stars it has been shown by Roberts and by Russell that the average densities of these stars is small, no more than one-eighth of that of the sun. On this and other grounds astronomers are of the opinion that stars are generally less dense than the sun, that is that they occupy a larger volume when of equal mass. The sun is only 1.4 times as dense as water, or half as dense as glass, while our earth is 5.5 times as dense as water, or 4 times as dense as the sun.

THE NUMBER OF THE STARS.

Stars are divided according to brightness in classes called magnitudes. First magnitude stars like Aldebaran are rare. A good example of the second magnitude is Polaris. Stars as faint as the fifth

or sixth magnitude can be seen with the unaided eye, according to the clearness of the sky and its freedom from the glare of cities. A difference of five magnitudes means a difference of a hundredfold in brightness. Thus sixth, eleventh, sixteenth, and twenty-first magnitude stars are respectively a hundred, ten thousand, a million, and a hundred million times fainter than first-magnitude stars. Our sun is about twenty-six magnitudes, or twenty-five billion times brighter than zero magnitude stars like Vega.

Do the stars increase in number without limit as we consider fainter and fainter ones revealed by larger and larger telescopes? To answer this question counts have been made of the actual numbers in the whole sky for the brighter magnitudes, and then of numerous patches of sky sufficient to give a fair average sample for the fainter magnitudes. In this way it has been found that up to the tenth magnitude the number of stars brighter than a given magnitude is about three times as great as the number brighter than the magnitude next preceding. From this point on the increase grows less and less rapid, so that of stars brighter than the seventeenth magnitude, the estimated number according to Chapman and Melotte, is only 55,000,000 instead of 1,800,000,000 as it would be if this constant ratio of increase prevailed. Up to the present time no thorough counts have been finished beyond the 17.5 magnitude, although by the aid of photography it is possible to observe stars as faint as the twenty-first magnitude with the great 60-inch reflector of Mount Wilson Solar Observatory. Arranging the information given by the counts in mathematical fashion, it appears that it is unlikely that any very considerable increase in the number of the stars will be found by observing stars fainter than the twenty-sixth magnitude, however large the telescope available.

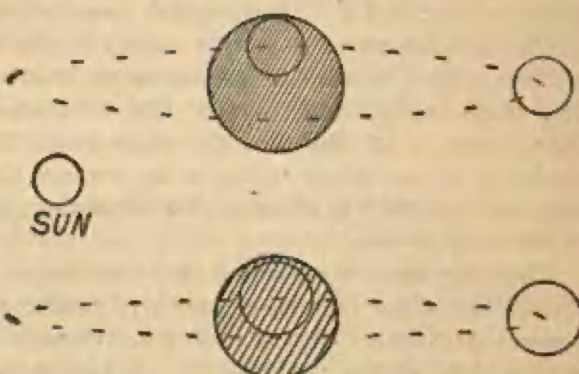


Fig. 3.—The system of R R *Draconis*. Diagram by Shapley. From Astrophysical Journal, vol. 37.

Stars at this limit are about as much fainter than those of zero magnitude as our sun is brighter, so that the brightest star (our sun) is twenty-five billion times twenty-five billion ($25\times10^9\times25\times10^9$) times as bright as the stars of the faintest class which are probably shining upon us in any considerable numbers. The total estimated

number of stars including this supposed limiting magnitude is probably between one and two thousand millions.

But why is it that there is a limit of numbers? Are we to suppose that there are no more stars, and that if our telescopes were sufficiently powerful to perceive those of twenty-sixth magnitude we could see all, little or big, that exist? Or are we rather to suppose that there is a limit of distance beyond which no star can be seen, however bright, so that though myriads without limit may exist, no single station in the universe is able to receive light from those beyond this limiting distance? It seems probable that the latter hypothesis is the true one, although astronomers would not be unanimous in saying so.

In recent years one bit after another of evidence has come out, tending to show that there is a light-absorbing medium in space. It is very rare. Dr. L. V. King has recently computed that the most probable measures of its effects on star brightness would be satisfied by assuming a density of the supposed absorbing medium in space less than one-trillionth part of that of the air. But even at this rate, space is so vast that the quantity of the supposed medium within a sphere whose radius is the average distance of the nearest star (α Centauri) is about 10,000 times the mass of the sun, which is startling if true.

There figures are of course very uncertain. But that there is in space here a particle, there another, yonder a hydrogen molecule, beyond still others, and that in the well-nigh endless path extending to stars of the twenty-sixth magnitude, whose light traveling 186,000 miles per second takes tens of thousands of years to travel to us, there would be found enough such particles to bar the doors of light, as a fog shuts out the sun—this seems reasonable.

THE DISTANCES OF THE HEAVENLY BODIES.[1]

By W. S. Eichelberger,
U. S. Naval Observatory.

Before any attempt was made by the ancients to determine the distance from the earth of any celestial body we find them arranging these bodies in order of distance very much as we know them to-day, assuming that the more rapid the motion of a body among the stars the less its distance from the earth; the stars, that were supposed to have no relative motions, were assumed to be the most distant objects.

The first attempt to assign definite relative distances to any two of the bodies was probably that of Eudoxus of Cnidus, who, about 370 B. C., supposed, according to Archimedes, that the diameter of the sun was nine times greater than that of the moon, which is equivalent to saying that, since the sun and the moon have approximately the same apparent diameter, the distance of the sun from the earth is nine times greater than that of the moon.

A century later, about 275 B. C., Aristarchus of Samos gave a method of determining the relative distances of the sun and moon from the earth, as follows: When the moon is at the phase first quarter or last quarter the earth is in the plane of the circle which separates the portion of the moon illuminated by the sun from the nonilluminated part, and the line from the observer to the center of the moon is perpendicular to the line from the center of the moon to the sun. If at this instant the angular separation of the sun and moon is determined, one of the acute angles of a right-angle triangle—sun, moon, and earth—is known, from which can be deduced the ratio of any two of the sides, as, for instance, the ratio of the distance from the earth to the moon to that from the earth to the sun. Aristarchus gives the value of this angle as differing from a right angle by only one-thirtieth of that angle, i. e., it is an angle of 87°, from which it follows that the distance from the earth to the sun is

[1] Presidential address before the Philosophical Society of Washington on Mar. 4, 1916.

nineteen times that from the earth to the moon. This method of Aristarchus is theoretically correct, but in determining the angle at the earth as being 3° less than a right angle he made an error of about 2° 50′.

Hipparchus, who lived about 150 B. C. and was called by Delambre the true father of astronomy, attacked the problem of the distances of the sun and moon through a study of eclipses. Assuming in accordance with the result of Aristarchus that the sun is 19 times as far from the earth as the moon, having determined the diameter of the earth's shadow at the distance of the moon and knowing the angular diameter of the moon he found 3′ as the sun's horizontal parallax. By the sun's parallax is meant the angle at the sun subtended by the earth's semidiameter and if $a =$ the semidiameter of the earth, $\Delta =$ the distance to the sun, and $\Pi =$ sun's horizontal parallax, the relation between these quantities is expressed by the equation:

$$\text{Sin}\ \Pi = \frac{a}{\Delta}$$

The next attempt to determine the distance of a heavenly body was made about 150 A. D. by Claudius Ptolemy, the last of the ancient astronomers and one whose writings were considered the standard in things astronomical for 15 centuries. To determine the lunar parallax he resorted to direct observations of the zenith distance of the moon on the meridian, comparing the result of his observations with the position obtained from the lunar theory. He determined the parallax when the moon was nearest the zenith, and also when it crossed his meridian at its farthest distance from the zenith. From his observations he obtained results varying from less than 50 per cent of the true parallax (57′.0) to more than 150 per cent of that value. According to Houzeau the definitive result of Ptolemy's work is 58′.7.

It is thus seen that the astronomers of 2,000 years ago had a fairly accurate knowledge of the distance of the moon from the earth, but an entirely erroneous one of the distance of the sun, the true distance being something like 20 times that assumed by them. This value of the distance of the sun from the earth was accepted for 19 centuries from Aristarchus to Kepler, having been deduced anew by such men as Copernicus and Tycho Brahe.

With the announcement by Kepler, early in the seventeenth century, of his laws of planetary motion it became possible to deduce from the periodic times of revolution of the planets around the sun their relative distances from that body, and thus to determine the

distance of the sun from the earth by determining the distance or parallax of one of the planets.

From observations of Mars, Kepler obtained the distance of the sun from the earth as about three times that accepted up to his time. His value, however, was but one-seventh of the true distance. About 50 years later Flamsteed and Cassini, working independently and using the same method as that employed by Kepler, obtained for the first time approximately the correct value of the distance of the sun from the earth. In a letter dated November 16, 1672, to the publisher of the Philosophical Transactions, Flamsteed says:

> September last I went to Townley. The first week that I intended to have observed ♂ there with Mr. Townley, I twice observ'd him, but could not make two Observations, as I intended, in one night. The first night after my return, I had the good hap to measure his distances from two Stars the same night; whereby I find, that the Parallax was very small; certainly not 30 seconds: So that I believe the Sun's Parallax is not more than 10 seconds. Of this Observation I intend to write a small Tract, when I shall gain leisure; in which I shall demonstrate both the Diameter and Distances of all the Planets by observations; for which I am now pretty well fitted.

During the two and a half centuries since Flamsteed's determination there have been more than a hundred determinations of the solar parallax by various methods. In the method used by Flamsteed the rotation of the earth is depended upon to change the relative position of the observer, the center of the earth, and Mars. Another method is to establish two stations widely separated in latitude and in approximately the same longitude. At one station the zenith distance of Mars will be determined as it crosses the meridian north of the zenith; at the other station the zenith distance will be determined as it crosses the meridian south of the zenith. The sum of the two zenith distances minus the difference in latitude between the two stations will give the displacement of Mars due to parallax. These two methods have been successfully applied to several of the asteroids whose distances from the sun are very nearly that of Mars.

The nearest approach of Venus to the earth is during her transit across the face of the sun, and these occasions—four during the last two centuries—have been utilized to determine the solar parallax. Here, as in the case of Mars, two different methods may be used, either by combining observations at two stations widely separated in latitude or at two stations widely separated in longitude.

The methods just described for obtaining the solar parallax, the geometrical methods, were made available, as has been said, by the discovery of Kepler's laws of planetary motion. Newton's discovery of the law of gravitation gave rise to another group of methods, designated as gravitational methods. The best of these is probably that in which the distance of the sun from the earth is determined from the mass of the earth, which in turn is deter-

mined from the perturbative effect of the earth upon Venus and Mars. This method is long and laborious, but its importance lies in the fact that the accuracy of the result increases with the time. Prof. C. A. Young says

> this is the "method of the future," and two or three hundred years hence will have superseded all the others, unless, indeed, it should appear that bodies at present unknown are interfering with the movements of our neighboring planets, or unless it should turn out that the law of gravitation is not quite so simple as it is now supposed to be.

A third group of methods of determining the distance of the sun from the earth, called the physical methods, depends upon the determination of the velocity of light in conjunction either with the time it takes light to travel from the sun to the earth obtained from observations of the eclipses of Jupiter's satellites or with the constant of aberration derived from observations of the stars.

In August, 1898, Dr. Witt, of Berlin, discovered an asteroid, since named Eros, which was soon seen to offer exceptional opportunity for the determination of the solar parallax, as at the very next opposition, in November, 1900, it would approach to within 30,000,000 miles of the earth. At the meeting of the Astrographic Chart Congress in Paris in July, 1900, it was resolved to seize this opportunity and organize an international parallax campaign. Fifty-eight observatories took part in the various observations called for by the general plan. The meridian instruments determined the absolute position of Eros from night to night as it crossed the meridians of the various observatories; the large visual refractors measured the distance of Eros from the faint stars near it, at times continuing the measures throughout the entire night; and the photographic equatorials obtained permanent records of the position of Eros among the surrounding stars. In addition long series of observations had to be made to determine the positions of the stars to which Eros was referred.

When several years had elapsed after the completion of the observations, and no general discussion of all the material had been provided for, Prof. Arthur R. Hinks, of Cambridge, England, volunteered for the work. The undertaking was truly monumental. He first formed a catalogue of the 671 stars which had been selected by the Paris congress for observation as marking out the path of Eros from a discussion of the results obtained by the meridian instruments and from the photographic plates. This done, with these results as a basis, a larger catalogue of about 6,000 stars had to be formed from measures on the photographic plates. He was then ready to commence the discussion of the observations of Eros itself. From 1901 to 1910 there appeared in the Monthly Notices of

the Royal Astronomical Society eight articles covering 135 pages giving the results of his labors.

From a discussion of all the photographic observations he obtained a solar parallax of

$$8''.807 \pm 0''.0027$$

a probable error equivalent to an uncertainty of about 30,000 miles in the distance to the sun.

From a discussion of all the micrometric observations he obtained

$$8''.806 \pm 0''.004$$

The observations with the meridian instruments gave

$$8''.837 \pm 0''.0185$$

a determination relatively much weaker than either of the others.

A parallax of 8''.80, the value adopted for all the national almanacs 20 years ago, corresponds to a distance of 92,900,000 miles. At present it seems improbable that another parallax campaign will be undertaken before 1931, when Eros approaches still nearer to the earth, its least distance at that time being about 15,000,000 miles.

TABLE I.—*Approximate distance from earth to sun as accepted at various times.*

Date.	Distance.
	Miles.
275 B. C. to 1620 A. D.	4, 500, 000
1620 Kepler	13, 500, 000
1672 Flamsteed	81, 500, 000
1916	92, 900, 000

When Copernicus proposed that the sun is the center of the solar system and that all the planets, including the earth, revolve around the sun, it was at once seen that such a motion of the earth must produce an annual parallax of the stars. Tycho Brahe rejected the Copernican system because he could not find from his observations any such parallax. However, the system was generally accepted as the true one, and the determination of stellar parallax or the distance of the stars became a live subject. Picard in the latter half of the seventeenth century, using a telescope and a micrometer in connection with his divided circle, showed an annual variation in the declination of the pole star amounting to 40''. In 1674 Hooke announced a parallax of 15'' for γ Draconis. About this same time Flamsteed announced a parallax of 20'' for α Ursae Minoris, but J. Cassini showed that the variations in the declination did not follow the law of the parallax.

The period which we have now reached is so admirably treated by Sir Frank W. Dyson, Astronomer Royal, in his Halley lecture delivered at Oxford on May 20, 1915, that I ask your indulgence while I quote rather freely from that source:

Thus in Halley's time it was fairly well established that the stars were at least 20,000 or 30,000 times as distant as the sun. Halley did not succeed in finding their range, but he made an important discovery which showed that three of the stars were at sensible distances. In 1718 he contributed to the Royal Society a paper entitled "Considerations of the Change of the Latitude of Some of the Principal Bright Stars." While pursuing researches on another subject he found that the three bright stars—Aldebaran, Sirius, and Arcturus—occupied positions among the other stars differing considerably from those assigned to them in the Almagest of Ptolemy. He showed that the possibility of an error in the transcription of the manuscript could be safely excluded, and that the southward movement of these stars to the extent of 37′, 42′, and 33′—i. e., angles larger than the apparent diameter of the sun in the sky—were established. * * *

This is the first good evidence—i. e., evidence which we now know to be true—that the so-called fixed stars are not fixed relatively to one another. It is the first positive proof that the distances of the stars are sensibly less than infinite.

At the time of the appearance of Halley's paper there was coming into notice a young astronomer, James Bradley, then 26 years old. He was admitted to membership in the Royal Society the same year that Halley's paper was presented. He was exceedingly eager to attack the problem of the distances of the stars. At length the opportunity presented itself. To quote again from Sir Frank Dyson:

Bradley designed an instrument for measuring the angular distance from the zenith, at which a certain star, γ Draconis, crossed the meridian. This instrument is called a zenith sector. The direction of the vertical is given by a plumb line, and he measured from day to day the angular distance of the star from the direction of the vertical. From December, 1725, to March, 1726, the star gradually moved farther south; then it remained stationary for a little time; then moved northwards until, by the middle of June, it was in the same position as in December. It continued to move northwards until the beginning of September, then turned again and reached its old position in December. The movement was very regular and evidently not due to any errors in Bradley's observations. But it was most unexpected. The effect of parallax—which Bradley was looking for—would have brought the star farthest south in December, not in March. The times were all three months wrong. Bradley examined other stars, thinking first that this might be due to a movement of the earth's pole. But this would not explain the phenomena. The true explanation, it is said, although I do not know how truly, occurred to Bradley when he was sailing on the Thames and noticed that the direction of the wind, as indicated by a vane on the masthead, varied slightly with the course on which the boat was sailing. An account of the observations in the

form of a letter from Bradley to Halley is published in the Philosophical Transactions for December, 1728:

When the year was completed, I began to examine and compare my observations, and having pretty well satisfied myself as to the general laws of the *phenomena*, I then endeavored to find out the cause of them. I was already convinced that the apparent motion of the stars was not owing to the nutation of the earth's axis. The next thing that offered itself was an alteration in the direction of the plumb line with which the instrument was constantly rectified; but this upon trial proved insufficient. Then I considered what refraction might do, but there also nothing satisfactory occurred. At length I conjectured that all the *phenomena* hitherto mentioned, proceeded from the progressive motion of light and the earth's annual motion in its orbit. For I perceived that, if light was propagated in time, the apparent place of a fixed object would not be the same when the eye is at rest, as when it is moving in any other direction than that of the line passing through the eye and the object; and that, when the eye is moving in different directions, the apparent place of the object would be different.

When Bradley's observations of γ Draconis were corrected for aberration, they showed, according to himself, that the parallax of that star could not be as much as 1''.0, or that the star was more than 200,000 times as distant from the earth as the sun.

On December 6, 1781, there was read before the Royal Society a paper by Mr. Herschel, afterwards Sir William, on the Parallax of the Fixed Stars. We read:

The method pointed out by Galileo, and first attempted by Hook, Flamstead, Molineaux, and Bradley, of taking distances of stars from the zenith that pass very near it, though it failed with regard to parallax, has been productive of the most noble discoveries of another nature. At the same time it has given us a much juster idea of the immense distance of the stars, and furnished us with an approximation to the knowledge of their parallax that is much nearer the truth than we ever had before * * *.

In general, the method of zenith distances labors under the following considerable difficulties. In the first place, all these distances, though they should not exceed a few degrees, are liable to refractions; and I hope to be pardoned when I say that the real quantities of these refractions, and their differences, are very far from being perfectly known. Secondly, the change of position of the earth's axis arising from nutation, precession of the equinoxes, and other causes, is so far from being completely settled, that it would not be very easy to say what it exactly is at any given time. In the third place, the aberration of light, though best known of all, may also be liable to some small errors, since the observations from which it was deduced labored under all the foregoing difficulties. I do not mean to say, that our theories of all these causes of error are defective; on the contrary, I grant that we are for most astronomical purposes sufficiently furnished with excellent tables to correct our observations from the above mentioned errors. But when we are upon so delicate a point as the parallax of the stars; when we are investigating angles that may, perhaps, not amount to a single second, we must endeavor to keep clear of every possibility of being involved in uncertainties; even the hundredth part of a second becomes a quantity to be taken into consideration.

Herschel then proceeds to advocate selecting pairs of stars of very unequal magnitude and whose distance apart is less than 5'' and making very accurate micrometric measures of this distance from

time to time. The first condition should give, in general, stars very unequally distant from the earth, so that the changing perspective as the earth revolves in her orbit would give a variation of the apparent distance between the stars, while the small distance, less than 5″, would eliminate from consideration entirely any effect upon this distance of the uncertainties in refraction, precession, nutation, aberration, etc. Herschel had already commenced the cataloguing of such double stars and in January, 1782, submitted to the Royal Society a catalogue of 269. This work did not enable Herschel to determine the distances of the stars but did enable him to demonstrate that there exist pairs of stars in which the two components revolve the one around the other. In 20 years he had found 50 such pairs.

Coming forward another generation—that is, to a time a little less than a hundred years ago—we find Pond, then astronomer royal, writing:

> The history of annual parallax appears to me to be this: In proportion as instruments have been imperfect in their construction they have misled observers into the belief of the existence of sensible parallax. This has happened in Italy to astronomers of the very first reputation. The Dublin instrument is superior to any of a similar construction on the Continent, and accordingly it shows a much less parallax than the Italian astronomers imagined they had detected. Conceiving that I have established beyond a doubt that the Greenwich instrument approaches still nearer to perfection, I can come to no other conclusion than that this is the reason why it discovers no parallax at all.

Within 15 years after this statement by Pond observations had been obtained which showed a measurable parallax of three different stars. The announcements of these results, each by a different astronomer, were practically simultaneous.

W. Struve, using a filar micrometer, determined the distance of α Lyrae from a small star about 40″ distant on 60 different days over a period of nearly three years. He obtained a parallax of $0''.262 \pm 0''.025$. Bessel, using his heliometer, determined the distances of 61 Cygni from two small stars distant about 500″ and 700″, respectively. He obtained for this star a parallax of $0''.314 \pm 0''.020$. Henderson, using determinations of the position of α Centauri by meridian instruments, deduced a parallax of $1''.16 \pm 0''.11$. All three of these results were announced in the winter of 1838–39 and indicate that the three stars are distant from the earth about 750,000, 650,000, and 200,000 times the distance of the sun from the earth.

TABLE II.—*Parallax of 61 Cygni.*

Mean date.	Observed displacement.	Computed from 0″.314.
1837.	″	″
August 20	+0.20	+0.18
September 14	+0.10	+0.08
October 12	+0.04	−0.05
November 22	−0.21	−0.22
December 21	−0.32	−0.27
1838.		
January 14	−0.38	−0.27
February 5	−0.22	−0.23
May 14	+0.24	+0.20
June 19	+0.36	+0.28
July 13	+0.22	+0.28
August 10	+0.15	+0.19
September 19	+0.04	+0.06

Table II exhibits the observed displacement of 61 Cygni by monthly means as given by Main from Bessel's observations. The last column gives the computed displacement on the assumption of a parallax of 0″.314. The reality of the parallax is seen at a glance.

In 1888, 50 years after the first determination of what we now know to be a true stellar parallax, Young, in his General Astronomy, gives, in a list of known stellar parallaxes, 28 stars and 55 separate determinations. Within the next 10 years the number of stars whose parallaxes had been determined about doubled, due principally to the work of Gill and Elkin.

Probably the most extensive piece of stellar parallax work in existence is that with the Yale heliometer. The results to date were published in 1912, and contained the parallaxes of 245 stars, the observations extending over a quarter of a century, the entire work having been done by three men—Elkin, Chase, and Smith. In selecting a list of stars for parallax work, an effort is made to obtain stars which give promise of being nearer than the mass of stars. At first the brighter stars were selected, and then those with large proper motions. The Yale list of 245 stars contains all stars in the northern heavens whose annual proper motion is known to be as much as 0″.5. Of these 245 stars, 54 are given a negative parallax. A negative parallax does not mean, as some one has expressed it, that the star is "somewhere on the other side of nowhere," but such a result may be attributed to the errors of observation or to the fact that the comparison stars are nearer than the one under investigation. It is safe to say, however, that somewhat more than half of the 245 stars have a measurable parallax.

Another series of stellar parallax observations, comparable in extent with the one just mentioned, is that of Flint, at the Washburn Observatory. This series includes 203 stars and extended from 1893 to 1905. These observations were made with a meridian circle, but

not after the method of a century ago. The observations were strictly differential, the general plan being to select two faint comparison stars, one immediately preceding and the other immediately following the parallax star, and to determine the difference in right ascension, the observation of the three stars occupying about five minutes. Here, as in the case of the Yale heliometer work, a large proportion of the resulting parallaxes are negative; somewhat more than half, however, were found to have a measurable parallax. The average probable error of a parallax was the same in each of these two pieces of work—about 0″.03. The progress of the work during the last two or three generations is given in Table III, which contains also a brief statement of the discoveries made during the preceding century, due chiefly to efforts to measure stellar parallaxes.

TABLE III.—*Approximate number of known stellar parallaxes.*

Date.	Astronomer.	Number of stars with known parallaxes.	Discoveries.
1718	Halley	(1)	Proper motion.
1728	Bradley	(1)	Aberration.
1750	do.	(1)	Nutation.
1790	Herschel	(1)	True binary systems.
1838		3	
1888		28	
1898		50 to 60	
1916		200 to 300	

[1] No parallax.

A generation ago photography entered the field of stellar parallax work, and has outdistanced all the previously employed methods for efficiency. In 1911 two publications appeared giving the results of photographic stellar parallax work, one by Russell, giving the parallaxes of 40 stars from photographs taken by Hinks and himself at Cambridge, England, the other by Schlesinger, giving the parallaxes of 25 stars from photographs taken mostly by himself at the Yerkes Observatory, Williams Bay, Wis. In speaking of these two series of observations, Sir David Gill said:

> On the whole, the Cambridge results, when a sufficient number of plates have been taken and when the comparison stars are symmetrically arranged, give results of an accuracy which, but for the wonderful precision of the Yerkes observations, would have been regarded as of the highest class.

Schlesinger has shown that with a telescope of the size and character of the Yerkes instrument "the number of stellar parallaxes that can be determined per annum, with an average probable error of 0″.013, will in the long run be about equal to the number of clear nights available for the work."

In other words, the Yerkes 40-inch equatorial used photographically determines stellar parallaxes with one-tenth the labor required with a heliometer and with twice the accuracy.

In July, 1913, stellar parallax work was undertaken with the 60-inch reflector of the Mount Wilson Solar Observatory, and at the meeting of the American Astronomical Society at San Francisco in August, 1915, a report on that work was made. The parallaxes of 13 stars have been determined, with a maximum probable error of 0″.010 and an average probable error of less than 0″.006, giving twice the accuracy of the Schlesinger results with the Yerkes 40-inch and from three to five times that obtained 15 years ago. What may we not expect when the 100-inch reflector gets to work on Mount Wilson?

At the meeting of the American Astronomical Society, to which reference has just been made, two other observatories reported upon their stellar parallax work. Lee and Joy, of the Yerkes Observatory, reported the parallaxes of 9 stars with a maximum probable error of 0″.014 and an average probable error of 0″.010; and Mitchell, of Leander McCormick Observatory, reported the parallaxes of 11 stars with a maximum probable error of 0″.012 and an average probable error of 0″.009.

The progress made in the accuracy of parallax results is shown at a glance in Table IV.

TABLE IV.—*The accuracy of stellar parallax determinations.*

Date.	Instrument.	Probable error.	Observers.
	Micrometric:		
1838	Dorpat refractor	0″.025	Struve.
1838	Königsberg heliometer	.02	Bessel.
1880–1898	Cape heliometer	.017	Gill and assistants.
1898–1912	Yale heliometer	.03	Elkin, Chase, and Smith.
1893–1905	Washburn meridian circle	.03	Flint.
	Photographic:		
1910	Yerkes refractor	.013	Schlesinger.
1915	do.	.010	Lee and Joy.
1915	Leander McCormick refractor	.009	Mitchell.
1915	Mount Wilson 60-inch reflector	.006	Van Maanen.

From these results it appears that any star whose parallax is as much as 0″.02, i. e., whose distance from the earth is less than 10,000,000 times that from the earth to the sun, should give a positive result when subjected to the treatment now employed in parallax investigations, and as 8 or 10 observatories are devoting their energies to stellar parallax work at present, the combined programs containing over 1,000 different stars, we ought soon to have lists of at least a few thousand stars whose parallaxes are known, where our present lists contain but a few hundred.

A CENSUS OF THE SKY.[1]

By R. A. Sampson, M. A., F. R. S.,

Astronomer Royal for Scotland.

[With 6 plates.]

It might seem to call for some remark, even some apology, that at a period like the present one, when all the ordinary interests of life disappear or are transformed, that we should meet as we had arranged to meet, and exchange with one another the different truisms of science.

There occurs to me a passage in a book by a celebrated private in the French Army, Anatole France's "Isle of Penguins"; one of his characters, deeply depressed by the perversity of the world, reflects somewhat as follows: "Since riches and civilization bring as many occasions for war as barbarism and poverty, since the folly and ill will of mankind are incurable, there remains one good deed to do, some wise man shall collect enough dynamite to blow this planet up. Then when it whirls in fragments across space some imperceptible alleviation will be felt in the universe and some satisfaction will be given to the universal conscience, which, indeed, does not exist."

While we feel as much as any this same savage indignation—Swift's *sæva indignatio*—that folly and ill will have still the power to throw the whole world off its bearings, and while we are all of us busily engaged in collecting enough dynamite to blow some parts of it to pieces, it is wise to remind ourselves that there are other things besides folly and ill will that are indestructible, and among these is the desire to increase natural knowledge. We are at no loss for precedents. Our Royal Society was initiated in the midst of civil war. The "Principia" was published a year before the Great Revolution. Kepler found in the Thirty Years' War no reason to

[1] Evening discourse delivered before the British Association Sept. 11, 1915. Reprinted, by author's permission, from The Observatory, a monthly review of astronomy, vol. 38, No. 493, Nov., 1915.

interrupt his study of the planetary motions, nor did Gauss in the invasion of Napoleon. Successive volumes of Mécanique Céleste came out, and bear evidence in their title-pages of the political changes of the French Revolution. Hevelius and Gassendi corresponded across a Europe in turmoil, and Newcomb worked with Delaunay at the theory of the moon while the Paris Commune raged almost to the doors of the observatory. Had science always waited to advance till times were quiet, it would have remained to this day uncommonly near to its starting point.

The subject to which I ask your attention for an hour to-night is not a small one. It is nothing less than the simplest comprehensive view of the whole universe. Indeed, it is a subject so vast that some have felt that in the study of it human interests would shrivel away and that as we looked steadily upon its extension we should be gripped with a kind of nightmare and feel ourselves shrinking and shrinking, and unless by violent effort we could throw it off we should seem in risk of vanishing altogether. But somehow that is not the case. Those who most study the matter and those who have lately contributed most to our knowledge are men well known to us, very human beings. Certainly a correct conception of the universe must govern the scale of ultimate values of all we do; but in the history of ideas it is remarkable that interest in it has for the most part of the time been satisfied with obvious fairy tales, has, in fact, been limited to the very narrow outlook of what we might immediately expect to accomplish, and has often combined in individuals an intense interest in the question, with a total disregard of any but the individual's point of view, as if even the "vasty halls" of cosmogony were an arena of sport, where the attempt was not so much to reach the goal as to gain a place for self-expression. As president for the time being of the Royal Astronomical Society, I keep a certain amount of involuntary touch with such people. "I should like to know, sir," one of these wrote to me severely the other day, "what steps are being taken to spread the true chronology and the truth about the deluge."

Well, perhaps that gentleman was a paradoxer; but it is interesting to bestow a side glance upon the way astronomy has been viewed by acute and catholic minds before the era when the commonplaces of diffused education had blunted a good many first-hand judgments. I shall not take you on a long excursion into history. Two or three pregnant examples will suffice.

Take Bacon's New Atlantis. In that remarkable country, which had flying men and submarines and scientific stockbreeding for the production of definite variations, it is true that they had a statue to "the inventor of observations of astronomy," but the systematic con-

templation of the heavens does not appear to have formed a part of their national scheme of study:

> We have high towers, the highest about half a mile in height; and some of them likewise set upon high mountains, so that the vantage of the hill with the tower is in the highest of them 3 miles at least. * * * We use these towers, according to their several heights and situations, for insolation, refrigeration, conservation, and for the view of divers meteors; as winds, rain, snow, hail, and some of the fiery meteors also. And upon them in some places are dwellings of hermits, whom we visit sometimes and instruct what to observe.

This passage is very disappointing to an astronomer. These hermits, with their magnificent equipment, state support, and boards of visitors, were nothing more than meteorologists.

Or, again, take Shakespeare. It is admittedly difficult to make out what views, if any, Shakespeare held on any subject, and I shall have to quote words put into the mouth of the light-minded Biron in order to make my point; but we know that the farcical figures of his plays are chiefly pedants and policemen; in particular, the pedant moved him to a school-boy ribaldry, and from two or three references I surmise that astronomy, as a science and apart from its poetic incrustations, struck him as yet another field for the preciosities of his ineffable pedants. "Study," says Biron—

> Study is like the heaven's glorious sun,
>   That will not be deep searched with saucy looks.
> Small have continual plodders ever won,
>   Save base authority from others' books.
> Those earthly godfathers of heaven's lights
>   That give a name to every fixed star
> Have no more profit of their shining nights
>   Than those that walk and wot not what they are.
> Too much to know is to know naught but fame;
> And every godfather can give a name.

That is all there is in it—giving names; science is nominalism. We may brush it aside, but, after all, it is a painfully shrewd hit against science.

Now, there was a very considerable and extended astronomy in Shakespeare's and Bacon's days. Copernicus's work De Revolutionibus was 50 years old. It was perhaps not much read, but for a century before devious voyages, lasting for months or years, to North and South America, to South Africa, and to India had made indispensable a working knowledge and command of its practice, and with the practice grew up a scientific interest.

In 1578 Mr. John Winter passed through the Straits of Magellan "in a good and newe shippe called the 'Elizabeth,' of 80 tonnes in burthen," as one of Sir Francis Drake's consorts. Neither the place nor the vessel can have been favorable to scientific abstraction, yet he determined his longitude there from an eclipse of the moon. The

passage (Hakluyt, Vol. VIII) is a gem of accurate astronomy, and I shall read it to you, for every point mentioned is relevant and the conclusion quite justified and near the truth:

> The 15 of September the moone was there eclipsed, and began to be darkened presently after the setting of the sunne, about sixe of the clocke at night, being then Equinoctial vernal in that country. The said eclipse happened the 16 day in the morning before one of the clocke in England, which is about sixe houres difference, agreeing to one quarter of the World from the Meridian of England, towards the West.

Now, take a long step from the sixteenth to the nineteenth century. Passing by a fastidious and academic writer like Tennyson, we find a mind as careless of fact and untrammeled by convention as Mark Twain deriving perpetual delight from the mere scope and scale of things astronomical in its revelation of the very size of the world as measured in millions upon millions of any units we can tell off. It may be hard to say exactly what this proves, but we may allow it to suffuse the continual plodder with a gentle glow of satisfaction, for without his continual plodding it would never have come to pass.

Undoubtedly the last word of astronomy must be heard before we can solve the problem of the philosophers upon its material side and place man in true relation to the universe.

I suppose it is evolution that has made us feel responsible for the universe, incurring thereby, it must be confessed, a very heavy responsibility with fate—a debt that would cause serious anxiety had not philosophy long since become reconciled to permanent bankruptcy. I mean that before evolution became one of our fixed ideas "man's place in nature" was an expression to which only an arbitrary meaning could be attached. There was no obligation to connect the phenomena of the universe in one long chain. Nothing is more illuminating as to our change of view than to read the words of one of the lesser lights of the eighteenth century—for example, Thomas Wright, of Durham, is an author who is often mentioned alongside Immanuel Kant as having foresight of the nebular hypothesis, the great evolutionary scheme of astronomy. Without depreciating the insight and the breadth of Wright's views on extended stellar systems the defect—the perfect defect of any evolutionary glimpse in them—strikes one now as an almost painful incompetence. We are sensible of the necessity of connecting all the parts of our system. That is the general interest in a survey of the sky, outside of professional interest in a difficulty overcome and of curiosity—which, indeed, is soon bored by mere magnitude—and that is the reason why we come back to it again and again, especially now that we are beginning from more than one avenue to approach some reliable, and one hopes some permanent, point of view.

That avenue which I would ask you to follow this evening is the most direct, the least artificial, and one would say the driest of all—mere enumeration, a census of the sky. But it is not dull. As I shall show you in a few minutes, the material dealt with is of compelling beauty, and, as scientific people, I hope it may interest you to have in brief review the considerable difficulties, instrumental and of organization; the many collateral questions that must be answered before any confident, or even approximate, reply can be given to the main question of how many stars there are and how they are distributed. And, finally, as British people, I think you feel a legitimate pride to know that this great and unobtrusive work, of central interest to astronomy, that I wish specially to describe to you is all British (including therein the Transvaal Colony) in design and execution; the plans made, cost provided, and very many of the photographs taken by an amateur, the late Mr. Franklin-Adams, a business man of London; the instrument designed by Mr. Dennis Taylor, and constructed by him at Cooke's works at York; the series of photographs completed at the Union Observatory at Johannesburg; and the counts performed and discussion made at Greenwich Observatory by Mr. Chapman and Mr. Melotte, two members of the staff. [Specimens of the Franklin-Adams chart were shown (pls. 1–6).]

You now see, more or less, the problem before you. To "give a name to every fixed star" is a task that we are not likely to undertake. The Arabs gave many of them proper names, which no doubt had some meaning, more or less substantial, but now passed on to the westerns with meaning, pronunciation, and accent alike in corruption, uncertainty, and disrepair, form a somewhat trying detail to the conscientious astronomer. Ptolemy adopted in his list a crude and picturesque description with reference to the asterism. Thus, in Leo: "The one on his muzzle," "the one in his throat," "the one at the tip of his front right claw," "the western one of the three on his belly," "the one at his heart named Regulus." It is a troublesome plan, even for the 1,000 stars of which he gives the places. Tycho, who was only incidentally a stellar observer, using the stars to fix his planets, carried on the method of Ptolemy. Not till the middle of the seventeenth century did Bayer in his Uranometria, introduce the device of attaching the Greek letters to stars in each asterism. The advent of the telescope, with Hevelius and our own Flamsteed, utterly outran any method except that of numbering. Lalande's Histoire Céleste in 1801 contained 50,000; Argelander's Durchmusterung in 1847, upward of 300,000 in zones from the pole to Dec. $-10°$. At each effort the object, if completeness was its aim, showed more mountainlike. In 1879, at the instance of the Astronomische Gesellschaft, Argelander's zones were revised by the cooperation of

many observatories in upward of 20 years. It hardly requires proof that with such resources as astronomy has ever commanded, or is likely to command, a complete enumeration upon these lines will never be attained.

If we are to attain a conspectus of the whole, now or ever, we must make a radical reduction in the demands of our problem. Now, in all these catalogues the places of the stars are recorded in their two coordinates, and the calculations made in each individual case which are necessary to allow for precessional change in the axes of reference. We can not dispense with knowing where the stars are, but if our interest is in their numbers and regional distribution, we can dispense with recording it precisely. And if we can take an elevated standpoint and eliminate the earth, like the Blessed Damozel, leaning on the gold bar of heaven, and see far below

> this earth
> Spin like a fretful midge—

why, then, we may dispense with the troublesome calculation of precession. There is almost nothing left then except to count.

But let nobody think lightly of the importance or the difficulty of mere counting. When the White Queen put to Alice the question:

> How many are one and one and one and one and one and one and one and one and one and one?

Alice does not appear to have been able to answer. Counting correctly is very difficult, because, so to put it, it requires from the mind a simultaneous hold upon the past, present, and future. Counting, on the other hand, done carefully is the only region of knowledge, even of mathematics, in which we can be perfectly sure we are not talking nonsense. Much that was formerly classed as geometry is now classed as nonsense. A circle has no properties until we say how it is generated, and we can not say how it is generated until we make up our minds about continuity: and continuity, to make it intelligible, is now explained in terms of discontinuity—that is, of counting. By counting infinity is made comprehensible, like an infinite perspective collected upon the narrow space of the retina, as a sequence of converging increments—countless in their number but countable in their sum or effect.

Counting by samples is another name for the theory of statistics, of averages, with their ramifications of probability, without which matters so disparate as life insurance and the kinetic theory of gases would be equally unmanageable.

I need not labor my point. In counting the stars you have to count a sum of which you can not tell in advance whether it will prove infinite or finite: you have to count by samples; you have to count by receding steps or grades as far as you can and then

infer the continuation; and, if these grades are incorrectly or debatably demarcated from one another, your results are liable to such enormous uncertainties that they can hardly be held to add anything to knowledge. To have performed this counting, as I believe it has been effectively and securely performed, is, in my judgment, a very great feat, one that would appropriately be taken as a landmark in the history of the mind; and I do not think I detract from this at all if I say that those who have actually done the work would not lay claim to more than to have well and truly performed a straightforward task by established methods. None the less, it marks a stage, a fact among many surmises, an achievement among many attempts.

Counting the stars is nothing else than the method of Herschel's star gauges supplemented by a due consideration of all the difficulties which he overstepped by intrepid assumptions. When Herschel set up his 20-foot reflector of 18-inch aperture it was mounted vertically in the meridian with a sweep of a little more than 2¼°, and he surveyed the sky in zones of declination, taking everything that came by, and, in particular, counting the density of the fields. These counts were the bases of his papers on the "Construction of the heavens," which showed that the sun was roughly in the center of an irregular disk-shaped universe of stars, researches that I have heard Sir David Gill describe as "almost inspired." But, if he was inspired, like other prophetic writers, we have to repose upon his genius, for criticism spoils him. It will not do now to tell us that a seventh-magnitude star may be generally taken as seven times as distant as a first-magnitude star. In the first place, calculation is astray—25 times would be more defensible—but, in the second, though we know that distance must raise magnitude, generally speaking, we are quite unable to verify the connection. But, most of all, though Herschel "looked farther into heaven than any man before him," for this purpose he did not look nearly far enough. His statement that in a field of 15′ diameter he counted some 70 or 80 stars, with occasional fields very much denser, would indicate that he reached to the thirteenth or fourteenth magnitude. The fifteenth magnitude more than doubles the fourteenth, the sixteenth nearly doubles the fifteenth, the seventeenth nearly doubles the sixteenth. How does the progression continue? Does it go on forever? Does it go on even as far as we can see?

No real advance upon Herschel's gauges could be made without photography, both because the record is permanent and so leaves you time to count and also because the faintness of the stars that you can reach is almost unlimited.

Let me now leave generalities and give you, as succinctly as possible, some details of the work I am describing.

The instrument consisted of a 10-inch lens of 45-inch focus, with a 6-inch lens of 27-inch focus, mounted, together with guiding telescopes, upon an equatorial mounting of the English pattern.

With the 10-inch lens, 17° by 17° upon the sky are depicted upon a plate 15 inches square, and to cover the whole sky upon this scale 206 plates were requisite. The exposure of each plate was 2 hours or 2 hours 20 minutes, so as to reach the faint stars. Northern plates were taken at Mervel Hill, near London; the southern at the Cape and afterwards retaken at Johannesburg.

There are certain defects in every lens which are practically incurable when a wide-angle field is desired, namely, curvature of the field and astigmatism or replacement of a point-image by two line condensations at different distances from the lens. It is the art of the lens maker and of the lens user to split the residual errors in the least harmful manner.

I show two slides taken from the same plate. The first shows the center, with images perfectly round, small, and defined. The second shows the corner. You see the elongations in two perpendicular directions succeeding one another separated by forms that suggest flights of beetles. That these forms are so little pronounced at some 10° from the center is the proof of the excellence of lens, focussing, and guiding. It is the practice to suppress them somewhat by sacrificing almost imperceptibly the definition at the center, so that the smallest images are actually not at the center, but half or two-third the radius away.

But this enlargement of image means diffusion of light, so that the instrument is less sensitive and the stars recorded are less numerous at the margin of the field than at the best focus. In matters of counting this is very important, because it would produce a systematic deviation. Accordingly, the average amount of this deviation was determined and allowed for.

It was proposed to count a sufficient number of plates to determine the number of stars, zone by zone, in each of eight zones of galactic latitude. Actually 30 plates were employed. They are all in the northern hemisphere, but lie both north and south of the galactic equator. In each count it was proposed to determine the number of stars of each separate magnitude, and here arose one of the most crucial, as well as difficult, points. The magnitudes recorded ranged down to the seventeenth, or nearly to the ten-millionth of the brightness of a first magnitude star. It was necessary to have the scale of magnitude correct over this wide space, because any deviation would here again become systematic, and, altering the number of stars in each grade, would altogether distort the estimated total of the vast number of those beyond the reach of counting. You will understand how difficult it was to establish an absolute magnitude scale when the

limiting brightness of stars recorded varies upon each plate with the purity of sky and the elevation above the horizon. I will only allude to this difficulty and say that a scale was determined and was applied to each plate in a way that is practically beyond criticism. Standard specimens of the results were photographed within the eyepiece of the measuring microscope for comparison with the plates and were used for the estimation of the magnitudes of all the stars. The counting then proceeded. Two computers were employed on the work and it occupied them for two years. Success depended very much on skill. After the counting had proceeded for a few weeks one of the earlier plates was recounted and the number of stars detected was increased by 50 per cent. The whole of these early plates were therefore repeated and, fortunately for finality, subsequent practice did not increase the numbers any more. Only the magnitudes from the twelfth to the seventeenth were counted, as the material was already available for stars brighter than the twelfth. These were found partly in some counts made at Harvard of stars from magnitude 2 to 4.5, partly in some counts of Schwarzschild for magnitude 5 to 7.5, but chiefly from the Greenwich Astrographic Catalogue from magnitude 9 to 12.5, and a special Greenwich photometry with the Franklin-Adams 6-inch lens for magnitude 6.5 to 9.0. The standard bases of all these, I need hardly say, were most carefully brought into adjustment. The results of this laborious work are contained in a table. (A diagram representing the table was shown on the screen.) B_m is the number of stars of magnitude m and brighter in each zone; its logarithm is charted here in place of the number in order to make the diagram more compact. In this diagram is contained the net outcome of the counts, the distribution of stars, zone by zone, for every magnitude.

All the eight curves, representing the eight zones, are independent, and their similarity, which strikes us at once, is convincing proof of their reliability. They tell us that in every zone the proportion of stars of the various magnitudes is the same, as far as the eye can follow. If we look closely into the numbers it appears that there is perceptible a slight gradual increase of the proportion of the fainter stars as the galaxy is approached. Beyond this there is a gradual increase in density in the whole number of stars in the zones, so that at the equator of the galaxy it is three times as dense as at the poles. The progress is quite gradual over the whole sky. The galaxy does not produce a sudden rise in the numbers, and simply drops into the statistical register of the whole. Statistically, in spite of the striking contrasts you have seen, the "divine disorder" of the heavens, there are no other features than this, a gradual condensation amounting at the limit to threefold toward the galaxy accompanied

by a slight relative increase of the proportion of the fainter stars. That is, the statistical description of the distribution of the stars when attention is diverted from their random features.

Passing now from the distribution in zones to the question of the total number of stars, the table below exhibits the data before us:

We see that as we take in successively the second, third, down to the seventeenth magnitude, the proportionate increase of numbers, which is at first three per magnitude, falls progressively until at the seventeenth it is less than two.

Beyond this it is almost wholly a matter of inference, but the progression is so steady that Mr. Chapman and Mr. Melotte have reduced it to a formula which, within the ascertained range, admits of very little latitude, and shows that at about the twenty-third or twenty-fourth magnitude we should have reached one-half of the total, and that this total would lie between one and two thousand millions.

I say it is a matter of inference, because hardly any material was available to carry on the counts. Two plates, however, were forthcoming, one by that keen observer, Mr. D'Esterre, and one from Mount Wilson, and these when counted confirmed the forecast numbers in reassuring fashion beyond the twentieth magnitude—that is to say, down to stars 100 million times as faint as those of the first magnitude.

Numbers and equivalent light of the stars.

Magnitude.	Number.	Equivalent number of first magnitude stars.	Totals to magnitude m.
−1.6	Sirius.	11	
−0.9	α Carinæ.	6	
0.0	α Centauri.	2	
0.0–1.0	8	14	33
1.0–2.0	27	17	50
2.0–3.0	73	18	68
3.0–4.0	189	19	87
4.0–5.0	650	26	113
5.0–6.0	2,300	35	148
6.0–7.0	6,000	42	190
7.0–8.0	22,500	56	246
8.0–9.0	65,000	65	311
9.0–10.0	174,000	69	380
10.0–11.0	426,000	68	448
11.0–12.0	961,000	60	508
12.0–13.0	2,020,000	51	559
13.0–14.0	3,960,000	40	599
14.0–15.0	7,820,000	31	630
15.0–16.0	14,040,000	22	652
16.0–17.0	25,400,000	16	668
17.0–18.0	38,400,000	10	678
18.0–19.0	54,600,000	6	684
19.0–20.0	70,000,000	3	687
All stars fainter than 20.0		3	690

There is the result, between one and two thousand millions—I suppose somewhere about as many as the people on the globe. I confess

to a feeling of a kind of relief in finding that the total is measurable and, comparatively speaking, moderate.

It may be well to add a few sentences in consideration of the validity of the conclusion, which is and must remain, an extrapolation beyond knowledge, a summation to infinity of a series not completely known.

We begin by admitting that we are dealing only with the sensible universe. There may be dark stars; in fact, we know that there are, because some of them have been detected in occulting the bright ones, as in the case of Algol. Naturally these are not counted. Nor do we reckon with the possible presence of absorbent matter in space, by which the magnitudes of all the stars seen would recede progressively, so that at the end of the series their light would be extinguished. Nor do we profess to unravel the details of globular clusters—we can not do everything. For that matter, there is infinite detail in a drop of blood or an atom of gas. We take the stars as we find them. The relevant question is the possibility of a sudden break or a gradual change in the progression after the 20 terms that have been so carefully examined.

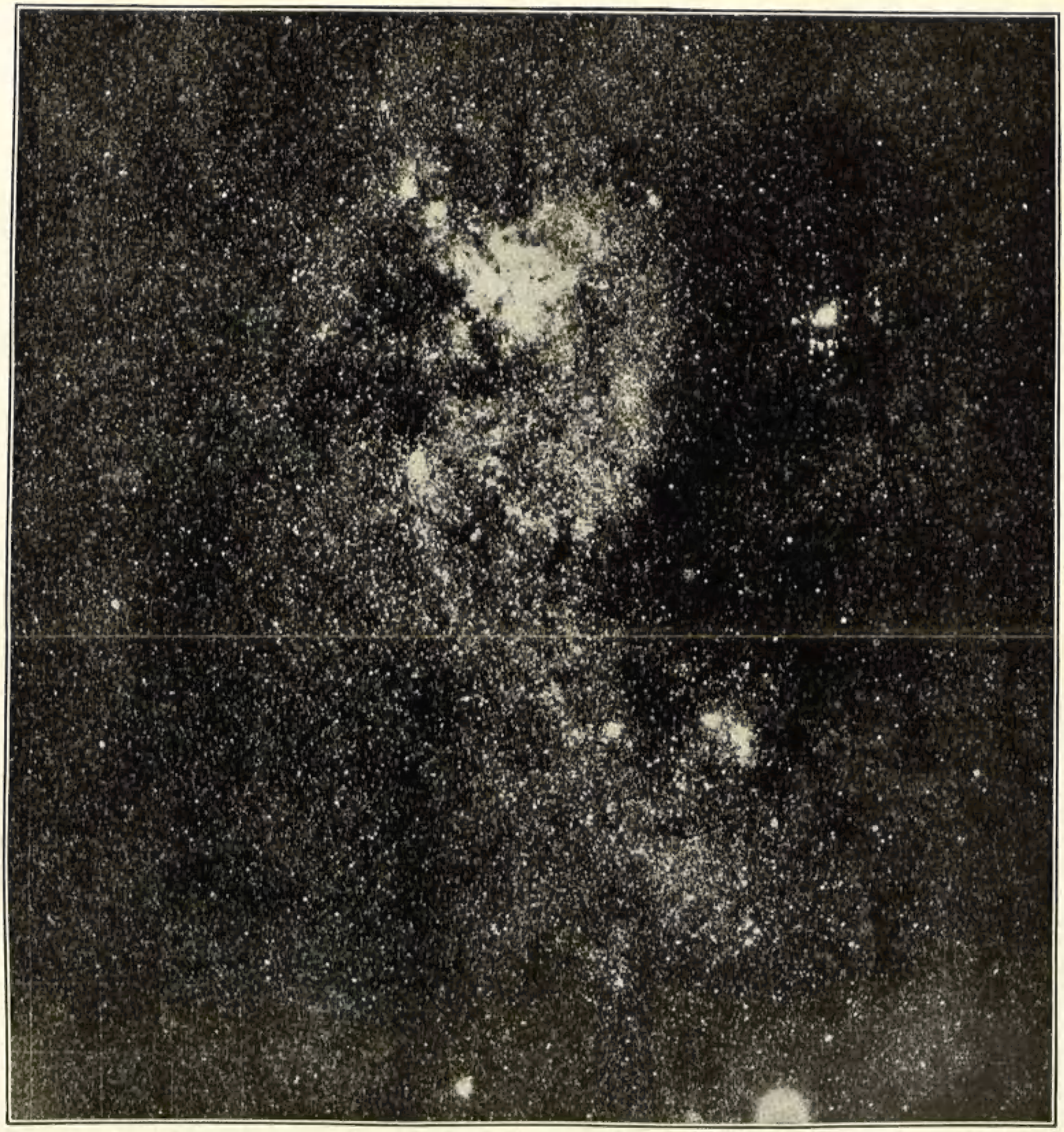
There would seem to be a certain kind of control in the total light received, but this proves illusory.

The total of starlight is a sensible amount, but it is very small. The table shown above is taken from a paper by Mr. Chapman. It shows that for the ascertained magnitude up to the twentieth the total light emitted is equivalent to 687 first-magnitude stars, which again has been put as equal to the hundredth part of full moonlight. If we include all the remaining stars, following the formula, the equivalent addition would be only three more first-magnitude stars. But this tells us very little, for if the progression were so altered that the total number were infinite the total light could easily still be finite, owing to the reducing effect of higher magnitude.

We leave off our summation at a point where each additional magnitude is adding more stars than the last. If this went on the number would be infinite. But, according to the formula, between the twenty-third and twenty-fourth magnitudes there is a turning point, after which each new magnitude adds less than before. The actual counts have been carried so near this turning point that there is no reasonable doubt of its existence. Given its existence, the number of stars is at least finite. That is a conclusion that I regard as open to very little doubt. As to the value of the sum, naturally we can be less positive. But all the indications of the earlier terms must be misleading if the margin between one and two thousand millions is not enough to cover the whole.

It is sometimes said that the British amateur astronomer, to whom in the past so much enterprising construction and so much

sound and brilliant observation is due, has disappeared. No doubt the growth of organization continues to add strength proportionately to the great observatories. I imagine that the number of excellent amateurs to be found at any one time was never large. While we can produce men like Mr. George Higgs or Mr. Franklin-Adams, whom unhappily we have lately lost, or Mr. D'Esterre, who happily is with us, we need not be anxious. Prof. Hale—himself, like Herschel and Gill, an amateur turned professional—once defined an amateur as a man who pursued astronomy because he could not help it. Mr. Franklin-Adams satisfied this test. Sir David Gill tells how, in 1903, he came to the Cape with the "incongruous double purpose" of curing the rheumatism and neuritis, which at that time almost incapacitated him, and of photographing the southern heavens. While the moon shone he retired to the sanatorium at Caledon, and at the end of a fortnight, against the best advice, he would emerge to sit up at nights and expose his plates. He has left the world a great gift and happily has placed it in trust with the best possible hands, those of Greenwich Observatory, and it has been dealt with there as it deserves, with the unassuming mastery that so well becomes that great house, by the astronomer royal, Mr. Chapman, and Mr. Melotte. We can not dispense with discussion and with theory, and I would be the last to depreciate them, but I think you will feel we always owe a special debt of gratitude and affection to the indefatigable, the truth-loving race of observers.



CENTER. R. A. $11^h\ 11^m$. DEC. $-60°\ 31'$. GALACTIC LONGITUDE 259°. LATITUDE +1°. TAKEN 1910, MAY 7.

Region near η Carinae. Bright stars shown: α Crucis (5, 45), δ Crucis (8, 101). λ Centauri (72, 58), and the neighboring stars appear to be involved in nebula. Cluster of stars around θ Carinae (142, 39). Nebula around η Carinae (148, 91). Cluster of bright stars, N. G. C. 3532 (115, 109). There are several small clusters. Many dark lanes, one being particularly noticeable along the southern edge of the field.

W

N  S

E

CENTER. R. A. $12^h 48^m$. DEC. $-61° 34'$. GALACTIC LONGITUDE 271°. LATITUDE +2°. TAKEN 1910, MAY 2.

Region around the Southern Cross. Bright stars shown: α Crucis (150, 62), β Crucis (116, 114), γ Crucis (150, 149), δ Crucis (177, 122). The visual magnitudes of β and γ Crucis are 1.5 and 1.6, respectively. γ Crucis, however, is photographically fainter, its spectrum being of class *Mb*. Star cluster κ Crucis (N. G. C. 4755) is at 105, 104. Cluster N. G. C. 4609 (124, 66). The Coal Sack appears about the center of the plate, a noticeable feature being the sharp-edged bay near α Crucis. The dark region gradually narrows into a lane extending to the southwest. There is a clustering of small stars with faint nebulosity at 51, 52. This is also shown on the next plate. There is a defect at 189, 128.

W

N  S

E

CENTER. R. A. $14^h\ 21^m$. DEC. $-60°\ 3'$. GALACTIC LONGITUDE 282°. LATITUDE 0°. TAKEN 1910, APRIL 10.

Region around α Centauri (84, 73). β Centauri (148, 78). Star cloud, with faint nebula (202, 20). Many rifts and dark regions. A lane is shown about a degree to the north of β Centauri: running at first in a northeasterly direction, it curves round and ends in a dark patch to the east of β Centauri.

N

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CENTER. R. A. $17^h\ 2^m$. DEC. $-45°\ 55'$. GALACTIC LONGITUDE 303°. LATITUDE +3°. TAKEN 1910, MAY 6.

Region around δ Normae. Bright stars: δ Normae (111, 94), γ Lupi (189, 143). Two stars involved in nebulosity (36, 41). Star cluster N. G. C. 6124 (63, 152). Some small clusters. Many lanes and dark regions.

N

E

W

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CENTER. R. A. 18h 0m. DEC. −30° 7′. GALACTIC LONGITUDE 329°. LATITUDE −5°. TAKEN 1910, JULY 29.

Star Cloud in Sagittarius. Bright stars are: γ Sagittarii (88, 96), δ Sagittarii (43, 103), ε Sagittarii (36, 44), η Sagittarii (55, 13), λ Scorpii (170, 6). Star Clusters M6, N. G. C. 6405 (156, 71), and M7, N. G. C. 6475 (118, 40). The Trifid Nebula, N. G. C. 6514 (35, 194) and Nebula N. G. C. 6523 (91, 175). This is probably the brightest part of the Milky Way, the original showing in the denser parts of the cloud, a continuous background of faint stars, the images of which are too close to be separated. There are innumerable dark lanes and channels forming a network over the cloud. A large lane runs from east to west across the lower (south) half of the plate. A fairly bright star at 91, 70 falls in a dark hole connected with the large lane before mentioned.

N

E  W

S

CENTER. 18h 52m. DEC.—30° 1′. GALACTIC LONGITUDE 333°. LATITUDE −15°. TAKEN 1903, SEPTEMBER 17.

Region around ζ Sagittarii. Bright stars: ζ Sagittarii (67, 101), σ Sagittarii (86, 143), τ Sagittarii (56, 126), φ Sagittarii (111, 134), α Coronae Australis (32, 8), γ Coronae Australis (59, 18), ε Coronae Australis (77, 18). The bright stars in Corona Australis fall in a dark region, from which a narrow lane extends in an easterly direction for quite 8°. There are traces of nebulosity round some of the bright stars, particularly the one at 71, 18. Globular Cluster N. G. C. 6723 (75, 23) falls just outside the dark lane. Globular Cluster M54, N. G. C. 6715 (86, 94). The large globular cluster M22, N. G. C. 6656 (137, 170) falls in a region covered by a number of curiously curved dark lanes.

GUN REPORT NOISE[1]—ACTION OF THE MAXIM SILENCER AND THE DIFFERENCE BETWEEN REPORT NOISE AND BULLET-FLIGHT NOISE EXPLAINED.

By Hiram Percy Maxim.

[With 7 plates.]

When a gun is discharged it is the common idea that there is a single noise heard—the report noise. That such is not the case, and that there are two entirely separate and distinct noises has been proved in a very interesting manner by the advent of the Maxim silencer. The history of the research work which led up to this device is very instructive and well worth recording.

When the work was undertaken, at the beginning the object was to annul report noise so that concealment of position, partly attained by smokeless powder, would be completed. When the firing line became invisible there was only left the report noise to indicate its position and also its strength or number of guns.

To attain this object, it was thought only necessary to check the suddenness of the release of the high pressure powder gases into the atmosphere. This pressure, in the caliber 30 United States service Springfield rifle, was approximately 10,000 pounds per square inch, when the base of the bullet emerged from the barrel muzzle. A device must be found which would present an unobstructed path for the bullet, but this path must not be available to the gas, at least easily.

The search for a path which would give a bullet an absolutely unimpaired passage, and yet would check gas at 10,000 pounds pressure per square inch, was a long one. For a year it persisted without results. Its successful ending came in a very interesting though extremely prosaic manner. The essential element was a hole which would be pervious to a rifle bullet but impervious to high-pressure gas. One morning, after taking a bath and pulling the plug in the tub drain hole, the water was given an accidental twist and the

[1] Reprinted by permission from Science Conspectus, vol. 6, No. 2, 1916.

familiar little whirlpool was created. It attracted the eye and finally the mind, since there was a hole through which water was passing but slowly, notwithstanding the fact that the drain plug was removed. In a flash the analogy was apparent. It was obvious that centrifugal force prevented the water from passing through the hole rapidly. If the powder gases in a gun were given the same vigorous whirling action, they would also acquire centrifugal force, and, if their outlet hole were located at or approximately at the center, they would exit relatively gradually. They simply could not exit until they had slowed down at least a little. The search was ended.

A little gas whirling device was quickly made and adjusted to the barrel of a rifle and the first shot fired was the first quiet rifle shot ever discharged from a high-power rifle.

When shooting was done in several different places, it began to be apparent that the noise depended upon the place, at least when a high-power rifle was used. It seemed to be impossible to eliminate a certain sharp "crack." The character of this crack was similar to a whiplash crack. It was entirely different from the more dull boom of the report. By accident it was found one day that this "crack" noise existed a long way down the range. A listener located at the 500-yard mark on a 1,000-yard range, detected the crack noise apparently overhead. This indicated immediately that it was connected with the bullet flight in some manner and was entirely separate and apart from the report noise.

Tests were made to bring out additional facts, and some of these are instructive. It was suspected that the bullet flight created a bow wave, creating a little zone of compressed air which moved out from the trajectory, and that this wave was heard by reflection. The person shooting the gun always heard a different noise from the person located at a distant point down the range. A terrain was selected on the extensive meadows on the Connecticut River bank below Hartford, where a series of clumps of bushes and small trees existed. There were three separate clumps in front of which the bullet from a Springfield service rifle could be made to pass. When the gun was fired, the listener at the gun heard three separate sharp cracks, and a low rattle of many minor cracks. This pointed fairly conclusively to the fact that the bow wave was reflected back from each of these clumps, and separate noises were heard from each, because they were separated by enough distance to give a distinguishable interval.

It was then thought that firing down a railroad track which ran along the open meadow, and had telegraph poles at regular intervals, would give a good test. This was done, and the result was a rapid succession of cracks, just as had been anticipated.

Then it occurred to the writer that if he could find a place to shoot where there would be no object from which reflection could occur, he ought to secure quiet shooting. It seemed a difficult condition to find until he bethought himself of getting up on a knoll away from trees and other objects and shooting straight up into the air. There would be no objects up in the air to reflect back the bow wave, and, if the theory were correct, such shooting should be almost entirely quiet. It was with much interest that a suitable place was searched out. One was finally found, and the first firings were felt to be of great moment. The first shot told the story, for the only noise was the puff of gas from the silencer, which sounded very soft and low. There was absolutely no bullet flight sound heard. The bow wave went on and on and never returned.

The next thing was to locate the limits of this bullet flight noise. It evidently persisted in certain guns while in others it never occurred, while in still others it occasionally occurred. Bullets from various cartridges were fired and it very soon developed that when the bullet velocity reached the velocity of a sound wave, the crack became noticeable. When the bullet velocity fell below the velocity of sound, there was no crack noise. The velocity of sound then appeared to be the critical point above which the ordinary bullet could never be fired quietly. It developed that the .22 caliber smokeless cartridges, except in the case of the long, gave quiet shooting, because their velocity was below 1,085 feet per second. The long cartridge appeared in some cases to be above this velocity though not always. There was evidently un-uniformity. The long rifle cartridge was always beautifully quiet, as was of course also the short cartridge. The .22 W. R. F. cartridge, which is a special high power, seemed to be just on the critical line. For example, in a box of 50 cartridges, about half would shoot without bullet flight noise, whereas the other half would make a loud crack. With all the larger caliber regular cartridges bullet flight noise occurred. By using special loads, they all gave quiet shooting. In some cases very heavy bullets were used, and the striking energy maintained in spite of the lower velocity. The reduced velocity of course reduced the distance at which accurate shooting could be accomplished. Two hundred yards always was possible, however, with bullet velocity of 1,000 feet per second, which is well inside of the critical point.

Before the question was considered settled, it was thought necessary to make various shaped bullets. Some were made of approximately perfect stream line shape. Others were made with a central hole all the way through the bullet. A copper gas check was used over the base when firing, and this fell off as soon as a bullet left the gun barrel. There never was a single piece of evidence upon which to hang a theory that the noise was in the slightest degree altered.

Then came the desire to actually see this peculiar manifestation and, incidentally, to conclusively prove the silencer. It was always a bit difficult to prove to the ordinary mind that the noise heard when shooting a rifle equipped with a silencer was made out in the air beyond the silencer and that the latter should not be held accountable.

The United States Navy, through their Ordnance Department, produced the best photographs which have been taken. These were made by mounting the gun in a dark room and setting up the camera with an open shutter along the line of bullet flight. Two wires leading from an electric condenser were dropped down directly beside the trajectory so that the bullet would short circuit these wires when it passed and create a spark, the duration of which was of radio frequency, possibly something approximately one five hundred thousandths of a second. This almost infinitely short exposure gave a clear photograph of the bullet and the variation in density of the air in the bow wave caused a variation in the refraction of the light, causing less light to fall where the pressure was high and more light where the pressure was low. Beautiful pictures of the noises made when the gun is discharged were obtained. Some of these are shown herewith. A series were taken showing the noises when the service rifle without silencer was fired and another series with the silencer. In the former, the report noise is shown, the birth of the bullet flight noise, and the bullet itself. In the latter the entire absence of report noise is shown and the very high efficiency of the silencer demontrated.

Plate 1 (photo I) represents the condition existing immediately following the emerging of the bullet at the muzzle of the Springfield rifle without silencer. The two vertical wires are shown and the bullet is enveloped in the mass of powder gases and can not be seen. The first wave appears to be made from a rush of air out of the muzzle and the main report noise wave is shown just back of it, being the broad dark line, irregular in places.

Plate 2 (photo J) represents conditions just a bit later. The bullet has emerged from a cloud of powder gases and has just begun the creation of its bow wave. It is shown puncturing the main report noise which shows particularly strong in this picture. By looking carefully the noise waves set up by flying particles of unburned smokeless powder can be seen.

Plate 3 (photo N) represents conditions still later and out beyond the disturbance of the blast of gas from the muzzle. The bullet flight bow wave has developed further and the greater velocity of the bullet over the report noise wave is very well shown. It is not plain at this time why the main report wave should be divided at the rear of the bullet. This completes the series of photographs taken without silencer.

Plate 4 (photo A) represents the first picture with silencer on the rifle. The bullet is shown emerging from the muzzle of the silencer, the bow wave of bullet flight noise is shown and there is absolutely no sign of any report noise. Indeed, there seems to be no disturbance created at all except the bow wave from the bullet.

Plate 5 (photo B) represents the conditions just a bit later. The bow wave and also a stern wave from the bullet is shown, the discharge from the silencer, but absolutely no report wave.

Plate 6 (photo E) represents a still later period, the bow wave being distinctly shown and the wake of the bullet. The stern wave has begun to disappear, for what reason it is not quite plain.

Plate 7 (photo F) represents a still later time and the wake of the bullet is the principle point of interest. This seems to partake of a spiral motion. The bow wave and the remnants of the stern wave are shown, but no report wave.

Having now shown the conditions existing at the muzzle of a firearm, equipped with a Maxim silencer, and proving as conclusively as seems possible that the noise of the gun is eliminated and that the only noise remaining is the bullet flight, we may ask the practical results. These have been very carefully studied from every imaginable angle. Field tests, accuracy tests, and tests at night have been conducted officially by war departments with bodies of troops equipped with silencers. Briefly summarized, these amount to the following:

1. The most important advantage on a shoulder rifle seems to be the diminution of sound on one's own firing line, which permits officers's commands to be heard during periods of the most rapid and concentrated fire. Without the silencer the human voice can not be heard.

2. The concealment of position of the firing line and the concealment of the number of guns comprising it. This is a natural advantage which might be imagined.

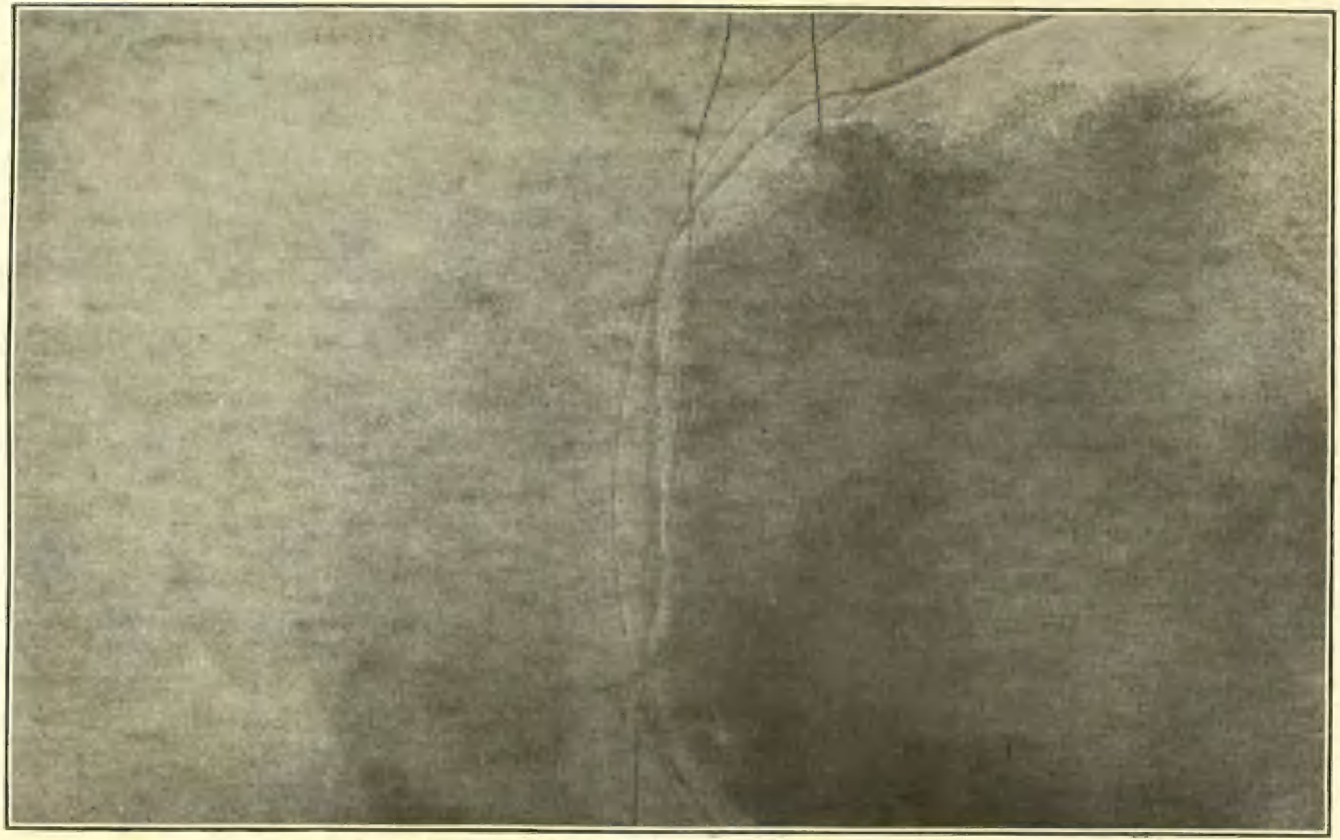
3. Improvement in marksmanship because of reducing the tendency to flinch. The elimination of the concussion entirely and the reduction of the recoil by 50 per cent makes the modern military rifle a much more gentle gun, and the rank and file in innumerable military tests always make higher scores than with the bare rifle.

4. Elimination of muzzle flash at night makes location of the shooter invisible. This is supposed to constitute an important military advantage.

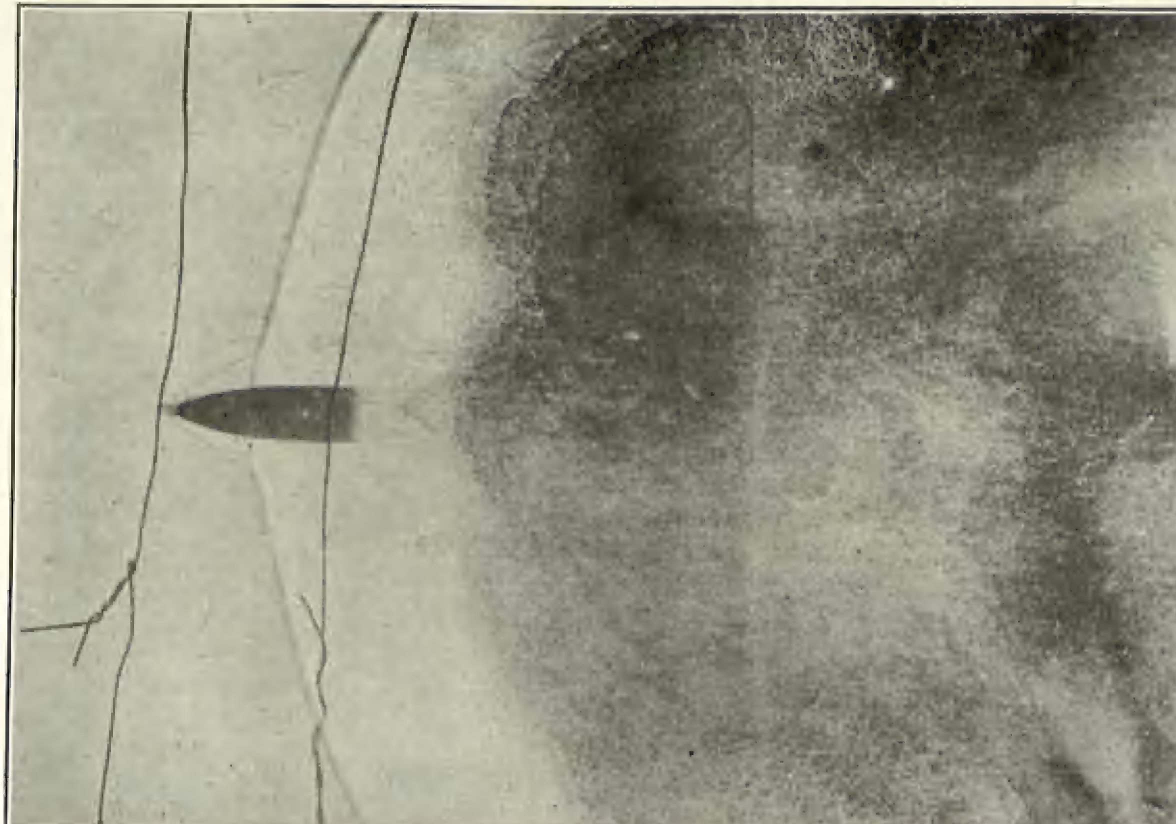
The aspects of a quiet shooting firearm in the case of assassins is of interest. We have seen that we can not secure quiet shooting unless we have bullet velocity below 1,085 feet per second. Except in 22-caliber this requires specially loaded cartridges for all calibers.

Furthermore, the silencer, being a gas check device purely and simply and applicable only to the muzzle, the ordinary revolver can not be silenced because of the joint between the cylinder and the barrel allowing the gas to escape if it is checked at the muzzle by the silencer. Thus the assassin's favorite arm is unsilenceable, to coin a word.

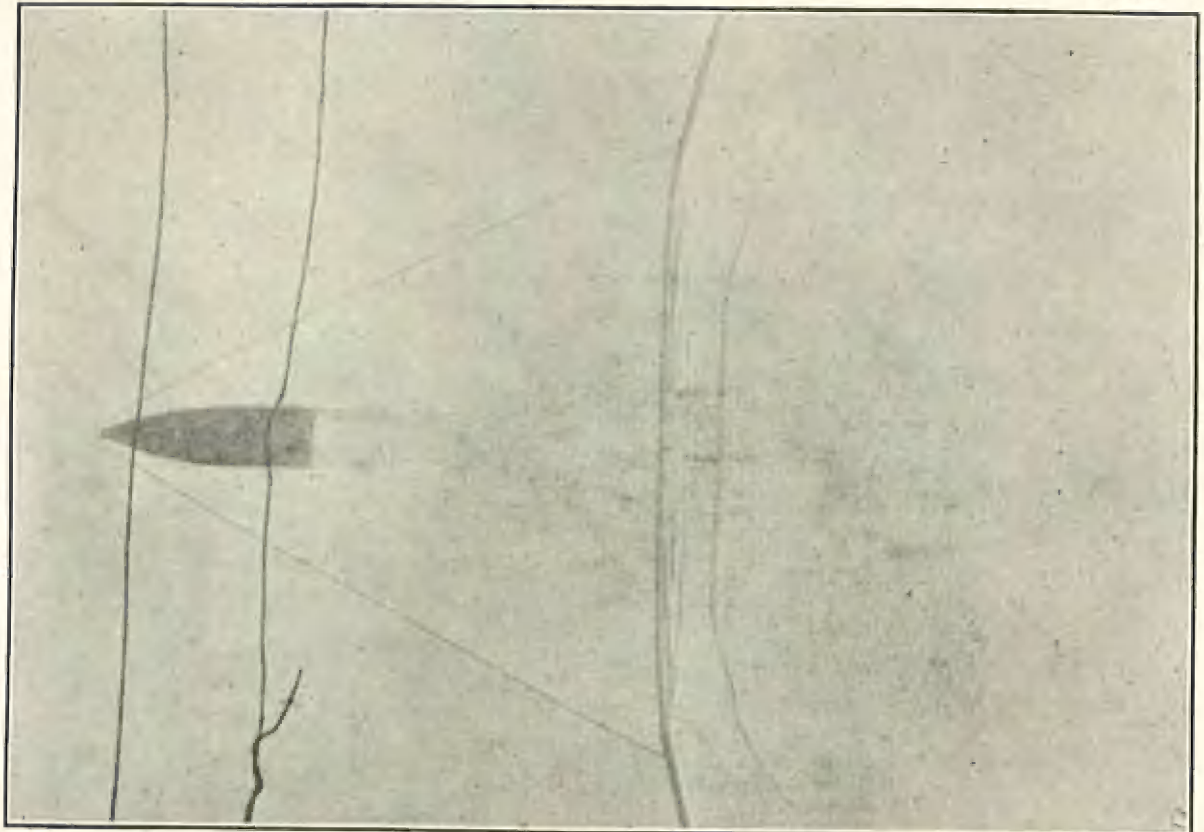
In the case of the automatic pistol it is almost an impossibility to attach the silencer and moreover the almost instantaneous opening of the breech permits a back blow and usually upsets the ejection of the empty shell enough to cause a jam. So we can not expect to see the automatic pistol silenced as things stand to-day. The assassin will have to design a small arm with a breech mechanism constructed on the lines of a rifle if he is to take advantage of any silencing device. Such a weapon does not exist at the present time.



PHOTOGRAPH TAKEN DIRECTLY AT MUZZLE OF RIFLE WITHOUT SILENCER.

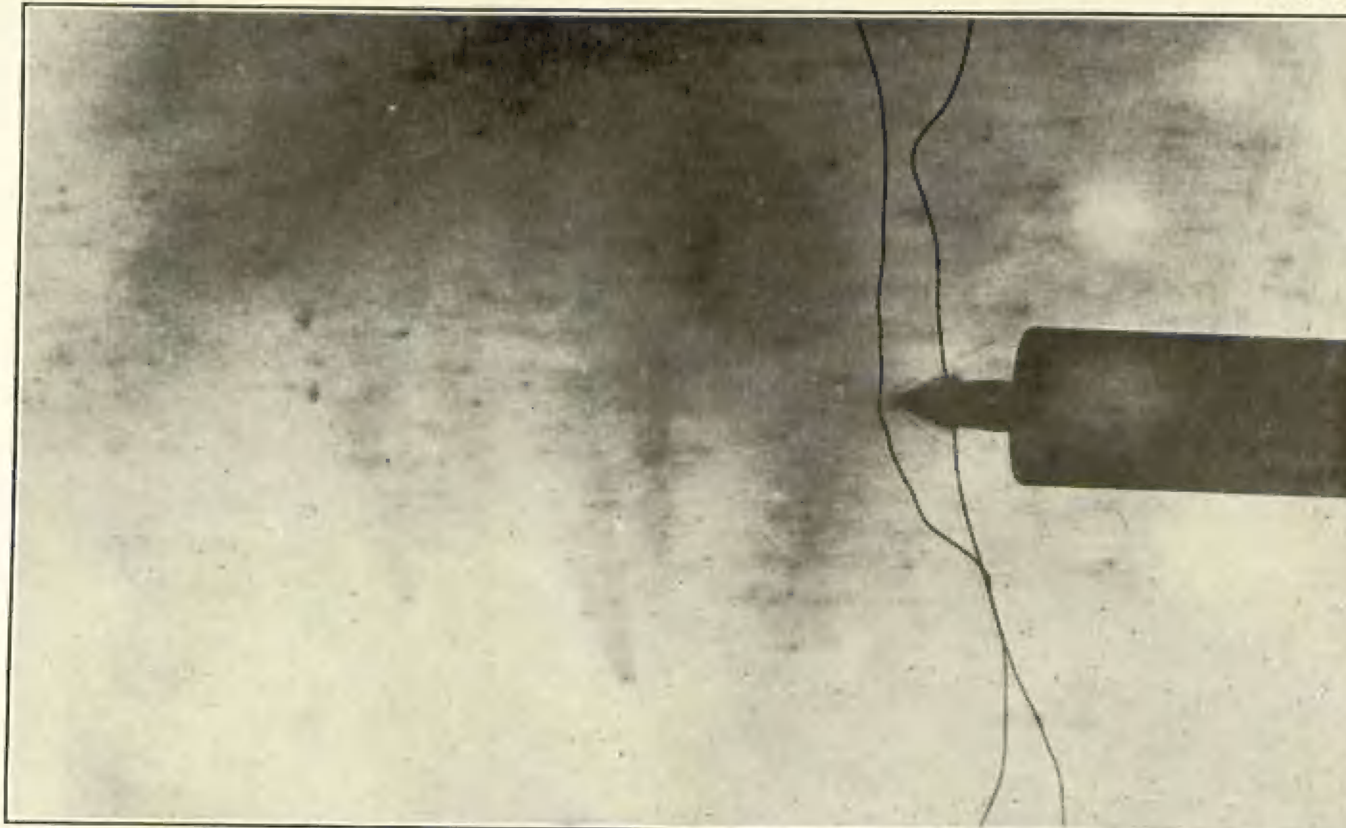


PHOTOGRAPH TAKEN ABOUT 4 INCHES FROM MUZZLE OF RIFLE WITHOUT SILENCER.

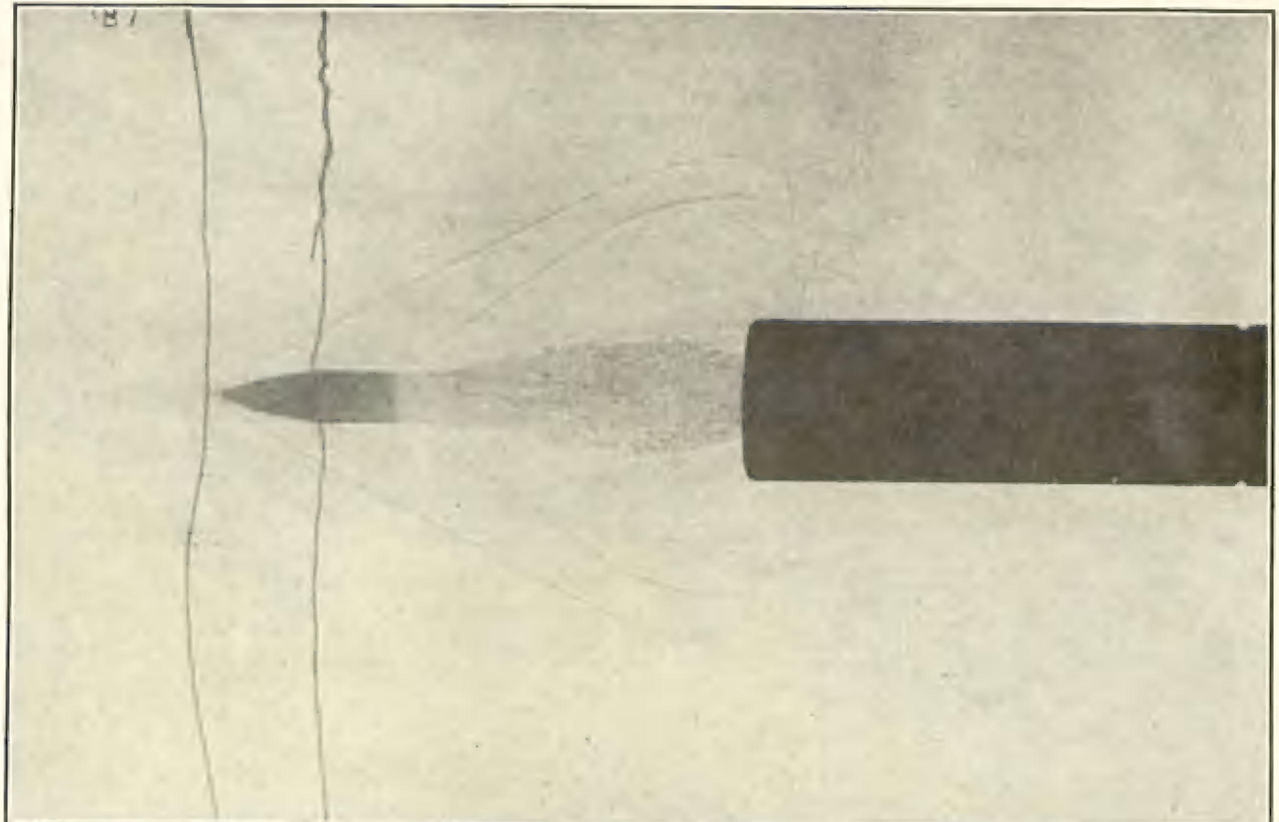


PHOTOGRAPH TAKEN ABOUT 8 INCHES FROM MUZZLE OF RIFLE WITHOUT SILENCER.

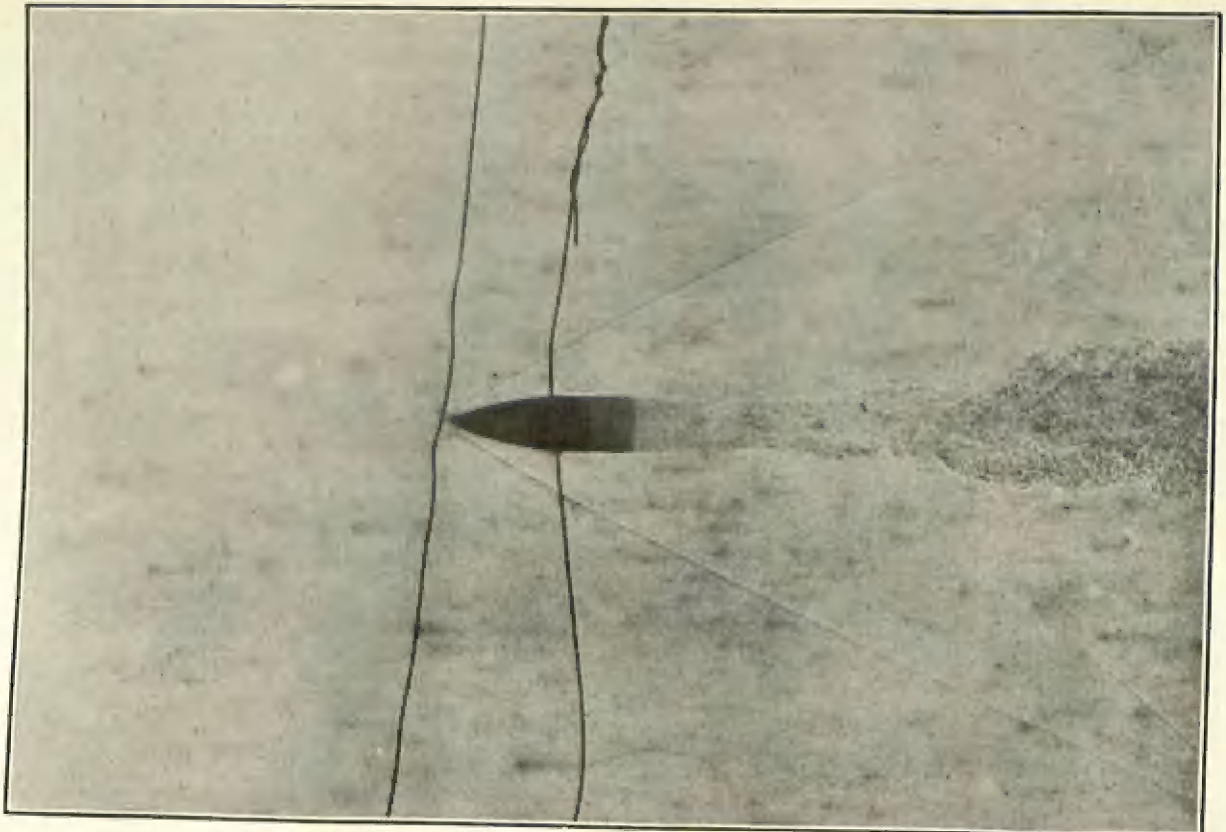
Note little grains of burning smokeless powder, each creating small bow wave of its own.



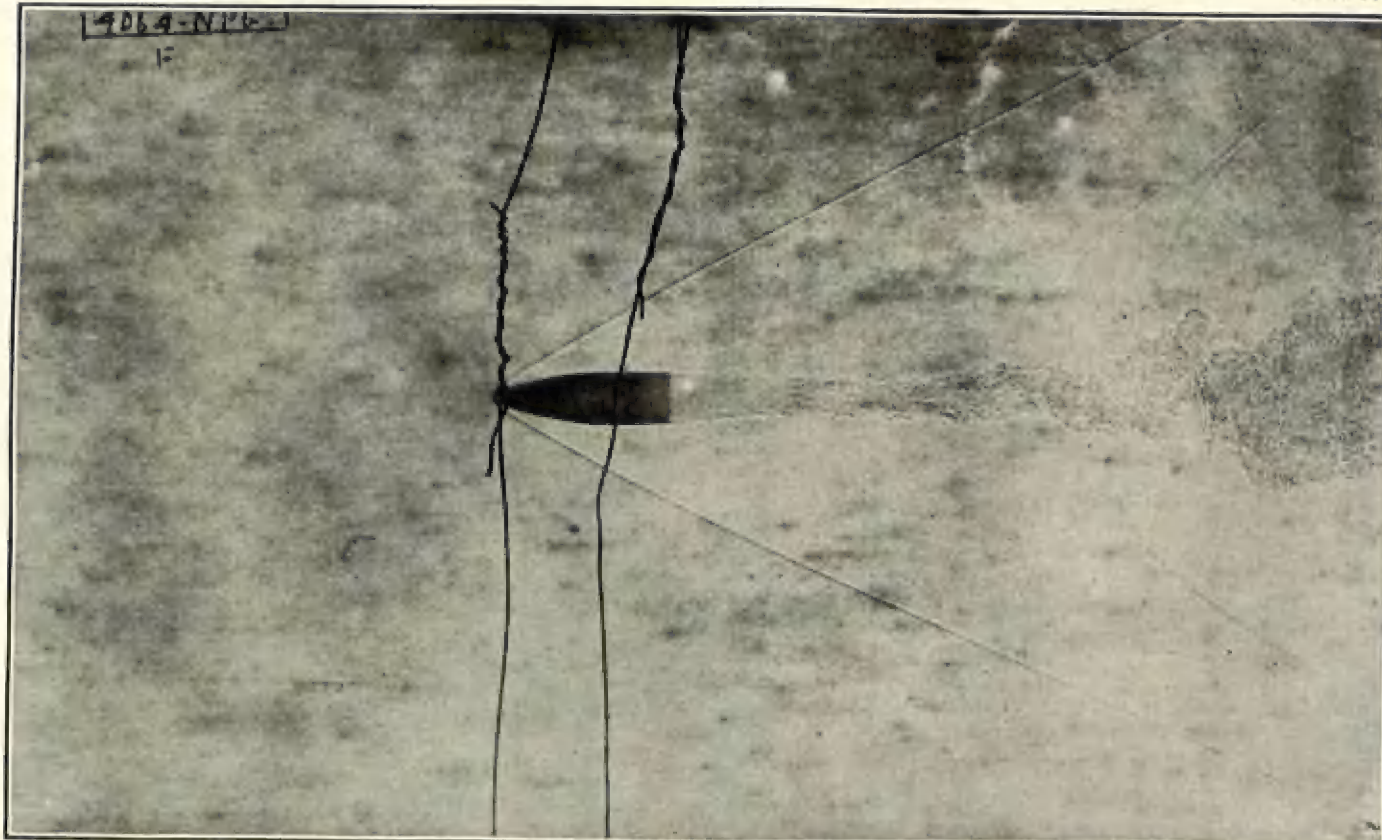
PHOTOGRAPH TAKEN DIRECTLY AT MUZZLE OF RIFLE WITH SILENCER.



PHOTOGRAPH TAKEN ABOUT 2 INCHES FROM MUZZLE OF RIFLE WITH SILENCER. SILENCER IS 1 INCH DIAMETER; BULLET IS .300 DIAMETER.



PHOTOGRAPH TAKEN ABOUT 6 INCHES FROM MUZZLE OF RIFLE WITH SILENCER.



PHOTOGRAPH TAKEN ABOUT 8 INCHES FROM MUZZLE OF RIFLE WITH SILENCER.

MOLECULAR STRUCTURE AND LIFE.[1]

By Amé Pictet,
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Of all the problems of nature the one deserving the most intense interest is undoubtedly that of life. Its solution concerns at the same time the whole range of natural and physical sciences, and it deserves to become the objective of all the exhaustive methods of research now at their disposal. And yet among the sciences biochemistry is the principal one upon which falls the task of this research. In fact, it is not at all doubtful that, if not life itself, at least the phenomena that it manifests in living things may be entirely of chemical origin.

But biochemistry itself is based on pure organic chemistry. In fact the fundamental condition for intelligently interpreting a phenomenon is to have exact knowledge of the agency by which it is unfolded. Now, it is the function of organic chemistry to supply us in this particular case with this knowledge by establishing the nature of the materials of which living things are composed.

To separate, to purify, to characterize, to analyze the innumerable compounds derived from animals and plants have been the primary objects of organic chemistry. But it has not stopped there; it has pushed on further to learn what may be called the constitution of these bodies; that is to say, the actual architecture of their molecules, the exact place that each of their atoms occupies, and the relations that those atoms bear to one another. It has succeeded in the great majority of cases, thereby accomplishing an immense task that may rightly be regarded as one of the most remarkable achievements of human intelligence up to the present time.

I hasten to add that the enormous amount of labor that these researches have required has not had its source alone in that speculative interest connected with all new knowledge. Chemists who

[1]Address at the opening meeting of the ninety-seventh session of the Société helvétique des Sciences naturelles, held at Geneva, September 12 to 15, 1915. Translated, by permission, from Revue Scientifique, Paris, November 13–20, 1915, and from author's revised pamphlet: "Extrait des Archives des Sciences physiques et naturelles, Geneva, 1915."

have broken up all the organic molecules, who have identified the constructive plan of these minute edifices, have been urged on by two other motives of a far more immediate import.

The first motive is the attractiveness of synthesis. It is acknowledged that the artificial reproduction of a natural compound can be brought about only when the composition of that natural compound is known in its minutest details. Whenever an attempt is made to proceed in any other way, to put the cart before the horse, as they say, and to work haphazard, the result is invariably a failure. The latest example of this is the fruitless attempts to make artificial rubber.

In the second place chemists have given their close attention to questions of composition because they are not slow to recognize the fundamental fact that all the properties of organic compounds—physical, chemical, and physiological—stand in intimate relation to this composition. It is not the quantity nor the nature of the materials employed in the construction of a building that makes of it a church, a theater, or a railway station. In the same way it is neither the specific kind nor the number of the atoms of a molecule that makes of an organic compound a coloring material, an antiseptic, or a perfume; it is simply the way in which the atoms are grouped one with the other. To know this method of grouping will be to possess the means of preparing at will and at one stroke any given new compound with predetermined properties.

A mass of relations of the highest interest between the composition and certain properties of substances have thus been established, such as their color, their staining quality, their density, their flavor, their polarization, their therapeutic action, etc. But all branches of this study have not been explored; in particular, no attempt has yet been made to connect their biological properties with the structure of molecules.

This is the subject that I should like to discuss at this time, and I begin by limiting it to the three following questions:

(1) Is there a relation between the chemical composition of a substance and the part it plays in the interior of a living organism?

(2) Is there a condition of molecular structure which makes a substance useful, inactive, or harmful in sustaining life, which makes it a food or a poison?

(3) Is there a like condition by which the material of a living cell is distinguished from that of the same cell when dead; in other words, does death result in changing the architecture of the molecules?

Before answering these questions it seems desirable to specify clearly with what particular phase of the theory of constitution my discussion will have to do and be assured I shall limit myself to

what is strictly necessary. It will be sufficient for the purpose of my demonstration to bring to your attention the principle of organic classification.

As the result of 50 years of patient researches it has been ascertained that the approximately 200,000 organic compounds now known, however great their diversity, belong, from the viewpoint of their molecular structure, to only two types.

In the first type, the atoms of which they are formed, whether saturated or unsaturated compounds, are joined in a nearly rectilinear chain of greater or less length. The central part of the molecule forms a sort of vertebral column to which in turn other atomic groups are joined laterally.

In the second type these same atoms are joined under the influence of similar attractive forces, but form closed chains. The structure of the molecule is now not a string of atoms but a ring. And on this ring similar circular groups are applied just as the tissues of a fruit are built up on its stone or kernel.

Hence we have the distinction between compounds with open chains and those with cyclic radicals. This distinction lies at the very foundation of organic classification. It corresponds, for example, to what in zoology is the division between vertebrates and invertebrates, and is not without analogy to it, for it is founded on the conformation of the structure and on the symmetry of the being, whether it be an animal or a molecule.

From a theoretic point of view the two great classes of organic compounds are separated by a great gap. But this is not insuperable. In many cases, by suitable reactions, it is possible to act on the molecules of substances in such a way as to close an open chain (cyclisation) or to break a closed chain (cyclolyse). Thus it is possible to pass experimentally from one type to the other.

It is true that this transition is incomparably easier in one case than in the other. One of the characteristics of the closed chains is their stability, considerable chemical energy being always required to disorganize them. On the other hand, cyclisation is more easily effected, although it demands a certain degree of energy, required for the bending of the rectilinear chain and the welding of its terminal atoms. What are the forms of energy needed to produce this result?

In the first place is heat. Berthelot first showed this by passing through red-hot tubes an entire series of open-chain substances. He thus obtained numerous cyclic compounds, and in particular the greater part of those that in combination constitute coal tar, a by-product of gas manufacture from which the modern chemist has obtained so many valuable derivatives. On the basis of these experiments, Berthelot likewise founded his well-known theory of the

formation of coal tar. According to this theory, coal in course of distillation is decomposed into very simple gaseous products with open-chain molecules, and these products by impact with the sides of the heated retort undergo cyclisation. We shall see hereafter what estimate should be given to this explanation.

But the cyclic compounds are found not in coal tar alone; they are met with in substances which have never been subjected to the action of great heat, such as petroleum. They are found above all in abundance in living organisms and, in particular, in plants. Here the agent causing the cyclisation is no longer heat energy, and a further search will be necessary to determine what it is.

First, however, permit me to make an observation. From what I said awhile ago it might appear that the properties of an organic compound must differ completely according to whether that compound belongs to the class of bodies with open chains or to those of cyclic form. But investigations so far recorded show this is not always the case. In both groups are found alcohols, acids and bases, substances having taste or odor and others not, substances that are poisons, and others that are harmless. Chemical industry draws indifferently from either group its perfumes and its explosives, and also its therapeutic medicines. Color alone seems to be found in connection with cyclic structure, and yet only to a limited extent.

It might be concluded that these properties are but slightly or not at all influenced by the architectural structure of the molecule; that they depend essentially on the nature of the external groupings which encircle this structure and which appear to be the same in both cases. This would be a strange fact. It is hard to understand how so essential a thing, from the theoretic viewpoint, as the structure of the molecule is not reflected in the fundamental properties of the material. But according to my personal observations this anomaly, which would be inexplicable, does not really exist. I believe I may, in a measure, affirm, on the contrary, that there is always a harmony in the fundamental properties of the material which are regulated by the nature, either cyclic or linear, of the molecular structure. These properties are the ones which come into play in all manifestations of life. It is this which I shall try to prove.

In order to study vital phenomena in their greatest simplicity, they must be observed not only in animals but also in plants. Consider then the green plant, the organism upon which devolves the task of transforming the mineral substances it contains into organic materials, and finally into living matter, which the animal needs only to decompose and oxidize in order to utilize the energy that they contain in a potential state.

What is the mechanism of this marvelous synthesis? Our present knowledge is very imperfect; but we do know the intermediary prod-

ucts through which this takes place. These are the formic and glycolic aldehydes, sugars and starch, numerous vegetable acids, asparagin, glycerin, fats, lecithins. These substances exist in all plants. They are found in each living cell, together with the proteins which are essential constituents of protoplasm. They rightly appear then as the foods of this cell.

However, if the constitution of these bodies be considered, the fact is striking that their molecules are made up only of open chains of atoms. None of them shows the cyclic structure. There is thus observed a fundamental relation between the constitution and the rôle of vegetable substances. All those that may be legitimately considered as the direct and successive products of assimilation, all those that contribute to the building up and nourishment of living protoplasms, belong to the first class of organic compounds.

But these substances are far from being the only ones that the vegetable kingdom furnishes us. Besides these the plant produces an infinite variety of others which human industry constantly searches for, not only to utilize them as foods, but also to profit by any of their other properties. Thus, for example, the great group of essential oils, turpentines, and camphors, many representatives of which constitute our perfumes or our highest prized condiments. There is also the long series of colorants and vegetable pigments, from chlorophyl to that interesting group of anthocyanins, or flower-pigments, the systematic study of which is being taken up by our former colleague, Willstätter. There are the various resins, the rubbers, the tannins, the glucosides, the various bitter or astringent principles. Finally, there are all those numerous nitrogenous and basic compounds grouped under the name of alkaloids and which, chiefly, because of their remarkable physiological action in the animal organism, have furnished our most valuable medicines. Is the part that these substances play in the plant the same as that of compounds of the first category? It is generally believed otherwise. And yet many physiologists still accept it to-day and see in these substances reserve food materials that the plant will utilize when the time comes to build up its tissues.

I do not at all share this view and for the following reasons: These substances seem to me not at all like the first, that is, indispensable to the development of plants, since many plants do not have them. They are not found, as are the others, inclosed in the seeds or in the roots. They are never met with in the living cell, from which they seem to be excluded, but are mainly in the tissues or in special receptacles where they are localized and stored separate from the great tract of protein formation. They do not disappear but on the contrary are accumulated during the life of the plant. They

are, then, certainly not intermediary products in the building up of the living protoplasm. Search must be made elsewhere than in a process of assimilation for the origin of these compounds which, without nutritive value for the plant are, however, often produced by it in considerable quantities. What then is their origin and their signification?

Some years ago in connection with this subject I advanced an hypothesis relating specially to alkaloids.

This hypothesis having been accepted with some favor, I extend it to-day to all compounds of the same character. I admit that, far from being products of assimilation, they are products of denutrition. They represent the losses of vegetal metabolism. They correspond to what among animals are urea, uric acid, glycocoll, biliary pigments, etc. It is, in fact, not conceivable that the biological synthesis of proteins, any more than synthetic operations in vitro generally, could be made with a theoretical yield, without leaving some secondary products, some residues which could no longer be utilized. Conversely, using the tissues, all the phenomena of assimilation and of combustion must produce in plants as well as in animals some corresponding losses, nitrogenous or otherwise.

All these products are not simply useless, but they are injurious to the maintenance of life. They represent poisons from which the organisms of both kingdoms must be freed at any cost under penalty of toxication. The animal can do this by expelling them; but the plant, deprived of excretory organs, can do this only very imperfectly. It must be content to retain them and is restricted to rendering them inoffensive by keeping them outside of the vital circulation and preventing them from reentering the living cell from which they have been expelled and from exercising their toxic influence on the protoplasm. And we find that it does this, for the compounds in question are never found actually present in the interior of such cells. The cell wall thus becomes a sorting place of useful and poisonous substances; it is permeable to the first, impermeable to the second. Can an explanation be given of the mechanism that regulates this sorting?

No physical characteristic (such as solubility, ionization, the colloidal or crystalline state) distinguishes the two kinds of substances from each other. No difference in chemical composition exists between them; they are formed of the same elements, which are those of protoplasm itself. It clearly follows, then, in my opinion, that only a difference of molecular structure can explain their opposite behavior. Let us now see what is known of their constitution.

Researches in this subject have led to the remarkable result, the final consequences of which are not yet known, that all these products are cyclic compounds. The carbon atoms of the turpentines, of

camphors, and of tannins, the carbon and oxygen atoms of the anthocyanins, the carbon and nitrogen atoms of chlorophyll and of all the alkaloids, are uniformly joined in closed chains.

We have seen that it is exactly the reverse with the nutritive substances of the cell. I see plainly in this different disposition of the atoms the reason why the molecules of one group should penetrate the living cell, and why those of another group would be excluded. A straight wire will penetrate a narrow opening if introduced endwise, but will not pass if made into a ring. Likewise the intermolecular passages of the cellular walls permit the passage of the flexible strings of open chains while they oppose the entrance of the massive and rigid rings which form the cyclic molecules.

Moreover the waste products of metabolism are primarily bodies with open chains, like the substances from which they are derived. It is therefore only after an impact that they acquire the cyclic structure which renders them inoffensive. There is here a reaction of the living plant against the toxic substances that it produces, and this reaction consists in a modification of the internal structure of these substances; the plant is defended against these poisons by cyclising them. There are therefore in the vegetal organism two parallel processes of synthesis, one which, reuniting the atoms by simple juxtaposition, forms the long open chains that will result in the formation of the complex molecule of the proteins, the other, carrying on a veritable street inspection, cleans the organism of all the detritus left over from the first synthesis, isolating all particles no longer available for constructive metabolism as well as those thrown off by destructive metabolism.

This hypothesis, being announced, it remains to verify it by experiment and to show how cyclisation operates in the plant. This is what I now proceed to do, at least so far as it applies to the alkaloids. Starting with the idea that, in organic synthesis, the best way to attain the end is to imitate nature, I have always sought in my attempts to artificially reproduce vegetable alkaloids to work under conditions as nearly as possible identical with those of the living plant. This idea has been followed in recent work in my laboratory by MM. Gams, Spengler, Kay, and Malinowski, and by Mlle. Finkelstein work has been carried on upon the synthesis of berberine and a number of the alkaloids of opium.

We have uniformly chosen as the starting point of our operations, on the one hand, such substances as are known to be formed in plants by the decomposition of the proteins, and, on the other hand, compounds, such as formaldehyde, which are derived in part from the carbonic acid of the air. In the condensation of these with each other we obtain certain cyclic alkaloids identical with those produced in vegetable tissues. I have thus succeeded, in collaboration

with M. Chou, in directly obtaining certain alkaloids, hydrolyzing in vitro the albumens themselves in the presence of formaldehyde.

It therefore seems well proved that the alkaloids have their origin in the plant by cyclisation of the products of decomposition of the proteins; and, by analogy, it is justifiable to attribute the same origin to all similar compounds.

In résumé, we observe a complete parallelism in the two grand divisions of organic compounds, between the form of their molecular structure and the rôle they play in the plant organism. Only compounds with open chains are capable of maintaining life in this organism, while compounds with closed chains, found in abundance in certain plants, are merely waste products, without nutritive value, rendered inactive by the fact of their cyclisation. An ideal plant ought to contain none at all. But a serious objection is at once raised to this conclusion. Any chemist or botanist will make it. He will say: In the list of substances which, in the plant, do not contribute to the formation of its protoplasm, you have omitted the most important, cellulose, that material, morphologically indispensable, which, in all plants, forms the cell walls and ducts and plays a fundamental rôle in the mechanical protection of the protoplasm by affording the covering needed for its organization into more or less rigid and resistant tissues.

It seems indispensable, continues my opponent, that the substance upon which this function devolves should possess a chemical stability sufficient to resist the multiple activities carried on within the plant. It must be independent of the general action of metabolism. If the ideas that you have developed are correct, they say, this independence would result from its molecular structure, and cellulose, like every other compound that the plant excludes from its vital activities, would possess the cyclic structure. But all chemical treatises place cellulose, as well as starch, among the open-chain compounds; and this fact alone is enough to overthrow the entire basis of your theory.

I recognize that this objection would be unanswerable if it rested on solid ground; that is to say, on an exact knowledge of the constitution of cellulose. But this constitution has not yet been determined, and the analogy with starch is not enough to establish it. I believe, on the contrary, that cellulose should be far removed from starch in the classification and be placed among the compounds of cyclic structure. A series of experiments that I have carried on with MM. Ramseyer and Bouvier offer proof of what I advance. These experiments bring out the following considerations:

The chemical phenomena which cause the decomposition of the plant after its death vary according to the conditions in which

they take place. If the plant be left to itself in the open air its nitrogenous materials at once undergo rapid putrefaction with the formation of ammonia, which is restored to the soil, and carbonic acid, which returns to the atmosphere. The nonnitrogenous materials, and in particular cellulose, resist much longer, but they also finally disappear, due to a slow combustion of which the agent, either direct or indirect, is the oxygen of the air.

If the dead plant, instead of being left in the open air, is more or less covered with earth, this action of the oxygen is retarded, and the formation of earth molds are aided, substances very little known from the viewpoint of chemistry but concerning which we do know they are products of the incomplete oxidation of cellulose and present some characteristics of phenol, that is, of cyclic compounds.

If, finally, these same vegetable materials are entirely protected from the action of the air, either by submersion in water or by being buried deep in the earth, as occurs in great geological displacements, they undergo none the less a slow transformation. But this is no longer an oxidation, it is a decomposition of a special character, the principles and agencies of which we do not know, although we do know perfectly the final products. These are our fossil fuels of various ages, as lignite and bituminous and anthracite coals. There is no doubt that in this instance it is cellulose which furnishes the essential material of coals. In this transformation the cellulose loses a part of its oxygen and hydrogen, and is consequently enriched in carbon. But this decomposition taking place at low temperature, affects only the periphery of the molecule; the carbon nucleus is not affected. It must therefore be admitted that the fundamental structure is the same in coal as in cellulose, and that determining it in the former establishes it at the same time in the latter.

Unfortunately, though coal has been used for two centuries as a fuel, though for a hundred years there have been obtained from it by distillation three products of such great industrial importance as illuminating gas, coal tar, and coke, yet there remains an almost total ignorance of its chemical nature. Can you infer its nature from the products of this distillation? It is known, as I have said, that coal tar is formed exclusively of cyclic compounds. It is the same with coke. The fact that it furnishes aromatic acids by distillation assures us that the atoms of carbon which compose it are united in closed chains. Can it be said that the same structure may be attributed to the materials as to their derivatives? Such an inference would seem to be absolutely unjustified, because during the distillation of coal these materials have been subjected to temperatures of 800° to 1,000°, and we are told by Berthelot's experiments that these temperatures are the cause of the cyclisation of all the open chains.

To avoid the force of this objection, it would be necessary to eliminate the cyclising action of heat during the decomposition of coal. This is what I have attempted to do with the assistance of my two expert collaborators. In operating the distillation of coal in vacuo, so as not to admit of an increase in temperature above 450°, we obtained a special coal tar and a new kind of coke. But in studying this vacuum coal tar and coke we have assured ourselves that each of them, like ordinary coal tar and coke, are exclusively of cyclic nature. We conclude from this that the cyclic compounds preexist in coal and certainly form its major part. From these experimental results there follow, in our opinion, the three following conclusions:

(1) Berthelot's theory of the formation of coal tar can not be considered as accurately interpreting the facts. All the derivatives of coal tar which chemical industry has utilized in such a brilliant manner, are no longer believed, as formerly, products of heat action. It is not at all to the heat of the gas jets that is due their well-known aromatic radical so rich in valuable properties. This radical already existed though in a more hydrogenated condition, in the plants of the carboniferous age. All chemistry of the aromatic compounds thus owes a dependence on plant chemistry.

(2) Vacuum coal tar is in reality nothing more than petroleum, having its odor, density, fluorescence, and weak rotatory power. All the definite compounds that we have derived from it are found to be identical with those other compounds isolated from the petroleums of Canada, California, and Galicia. We therefore verify for the first time, a relation of a chemical order between these two natural products of such high importance, coal and petroleum. Does this relation imply a common origin, and can it serve as an argument for those who claim that petroleum, like coal, is of plant origin? For my part I believe so, but to enter into a discussion of that point would be too far from my subject.

(3) If coal, as we believe we have demonstrated, is formed of a mixture of cyclic substances, one could hardly fail to attribute the same structure to cellulose, which, of all the substances contained in plants, is the one that plays the greatest part in the formation of coal. The objection that my opponents would make in this respect therefore falls and my hypothesis conversely finds a new example for its support.

With one span we will now bridge the entire distance separating the first products of plant assimilation from its final product, namely, living matter. And it should be understood at the outset that I employ this term "living matter" only as an abbreviation, and to avoid long circumlocution. You should not, in reality, attribute

life to the matter itself; it has not, it can not have both living molecules and dead molecules. Life requires an organization, which is that of cellular structure, but it remains, in contradistinction to it, outside the domain of strict chemistry.

It is none the less true that the content of a living cell must differ in its chemical nature from the content of a dead cell. It is entirely from this point of view that the phenomenon of life pertains to my subject. It is therefore from this view point that it remains for me to examine whether the ideas I have presented can be used for its interpretation.

A living cell, both in its chemical composition and in its morphological structure, is an organism of extraordinary complexity. The protoplasm that it incloses is a mixture of very diverse substances. But if there be set aside on the one hand those substances which are in process of assimilation and on the other those which are the by-products of nutrition, and which are in process of elimination, there remains only the protein or albuminous substances, and these must be considered, if not the essential factor of life, at least the theater of its manifestations. These alone, in fact, possess those two eminently vital faculties of building up their molecules within the cell itself and of reacting to the slightest influences of a physical, chemical, or mechanical nature. They are therefore classified among the most reactive organic compounds that we know, and it is their very reactivity which makes them the supporters of vital phenomena. During the life of the cell they are in a state of perpetual transformation, and are found in a state of stable equilibrium only upon the death of the cell; or, better to say, this death is only the result of the stabilization of the protein molecules.

Is this stabilization a chemical process, in the sense that it brings about a modification of the molecular structure? To ascertain if such be the case, and what this modification is, it is necessary to know the constitution of both living albumen and dead albumen. Chemistry, however, is totally ignorant, or nearly so, of the constitution of living albumen, for chemical methods of investigation at the very outset kill the living cell. The slightest rise in temperature, contact with the solvent, the very powerful effect of even the mildest reactions cause the transformation that needs to be prevented, and the chemist has nothing left but dead albumen.

It is therefore only dead albumen that chemistry has been able to study. Thanks to the investigations of a host of eminent men of science, we now know, if not in all its details, at least in great part, the constitution of the albumens. It is known in particular from the special point of view that occupies our attention, that the extremely complex molecule of these bodies is formed of an assemblage of a

very great number of chains, some of which are formed wholly of carbon atoms, others of atoms of carbon and of nitrogen, but which for the most part are of closed chains. The albumens obtained from dead tissues are therefore of cyclic structure.

Is it the same with those albumens which still form an integral part of living protoplasm; and how do we know this? A very interesting observation of Loew will be offered as a beginning of my answer to these questions. Loew has stated that all those chemical reactions which in vitro are susceptible of attacking the aldehydes and the primary bases, or which act on the aldehyde and aminogen groups which characterize them, that all these reactions, are invariably poisonous to living protoplasm. These same reactions are, on the other hand, without any influence on dead albumen. Loew logically concludes from this that the molecule of living albumen incloses the said groups, while the molecule of dead albumen no longer possesses them.

These two groups of atoms, throughout the whole extent of organic chemistry, possess some very active though opposite characteristics which tend to react upon one another by an interchange of their elements. This exchange does not take place in living albumen, since the two groups are here in a coexistent state; this becomes effective on the death of the cell, for neither of the two groups can any longer be discovered in dead albumen.

The stabilization of the protein molecule would therefore be due, according to Loew, to the saturation of the one by the other of these two groups. This observation appears capital to me; but its author has not at all, it seems to me, followed the conclusions to their end. I will try to do this for him.

On account of their very nature these groups of atoms of which I speak could not in any case form an integral part of a closed chain. Both being monovalents they could form part only of open chains. Their existence in living albumen, therefore, necessarily implies the presence of these chains. But the union of two atomic groupings forming part of an open chain could not be made unless there was a closing of this chain; at the same time the disappearance of two active groups necessarily also involves the loss of a part of the activity of the resultant complex, just as a man who joins his hands or crosses his arms loses to a great extent his means of action.

The stabilization of living albumen, therefore, involves a cyclisation. In closing the open chains in themselves the albumen of the cellular protoplasm enters into equilibrium and repose. Its period of activity is ended in the same way as that of all the substances which have contributed to its maintenance. For those and the others cyclisation is death.

In this case it is a momentary death, understand, and destined to be followed after more or less delay by a resurrection which brings back into circulation the temporarily inert atoms. It is clear, in fact, that if all cyclised molecules should indefinitely persist in that state all life would soon disappear from the surface of our globe, but then all that I have said applies only to organic compounds which form part of the living plant. When a plant dies other agents intervene which proceed more or less rapidly to the destruction of all the molecules and to a general decyclisation. The dead plant forthwith becomes a prize of the microbes of putrefaction, which attack its albumens, and of the oxydizing ferments which burn its cellulose. Or we may substitute the digestive ferments of herbiverous animals, which are equally cyclolitic. Here, as elsewhere, the vegetable and animal kingdoms are complements one of the other and interdependent, and these same atoms, passing from one to the other in the aggregate of diverse structures, sustain the eternal existence of both.

Such are the considerations that I proposed to submit to you on the relations existing between molecular structure and life. I have raised only a small corner of the veil that hides the mystery, but I believe I have answered the three questions with which I began, by showing: (1) That the phenomena of life are dependent upon a special structure of the organic molecule; (2) that only the disposition of atoms in open chains permits the maintenance and the manifestations of life; (3) that the cyclic structure is that of the substances which have lost this faculty; and (4) finally that death results, from the chemical point of view, by a cyclisation of the elements of the protoplasm. The serpent which bites its tail, the symbol of eternity among the ancients, might well become, to the modern biological chemist, the symbol of death.

I have spoken only of plant chemistry. It remains to examine whether my interpretation can apply likewise to the phenomena which take place in the animal organism. But I can not, nor do I wish to, longer tax your patience, for I have already taken too long a time in testing it.

IDEALS OF CHEMICAL INVESTIGATION.[1]

By Theodore William Richards.

In the present address I shall try to put before you some of the ideals of chemical investigation. Our present efforts and our hopes for the future are founded upon past acquisitions; therefore I shall call your attention first to the gradual development of chemistry.

Less than three centuries ago an outspoken student of nature sometimes faced the grim alternatives of excommunication, imprisonment, or death. To-day he no longer needs to conceal his thoughts in cryptic speech or mystic symbolism. Although the shadow of incomprehensibility may still darken the langauge of science, mystery is no longer necessary to protect the scientific investigator from persecution. The generally recognized value of the truth within his domain gives him the right to exist.

The courage needful for the task of addressing this august assembly on a topic concerning chemistry is, therefore, of a different order from the courage required for such a task in the days of Galileo. The problem to-day is not how to obscure the thought, but, rather, how to elucidate its inevitable complications.

Modern chemistry has had a manifold origin and tends toward a many-sided destiny. Into the fabric of this science men have woven the thought of ancient Greek philosophers, the magic of Arabian alchemists, the practical discoveries of artisans and ingenious chemical experimenters, the doctrine of physicists, the stern and uncompromising logic of mathematicians, and the vision of metaphysical dreamers seeking to grasp truths far beyond the reach of mortal sense. The complex fabric enfolds the earth—indeed, the universe—with its far-reaching threads.

The history of the complicated evolution of chemistry is profoundly significant to the student of human thought. Long ago, at the very dawn of civilization, Hindu and Greek philosophers were deeply interested in the problems presented by the nature of the uni-

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[1] Oration delivered before the Harvard Chapter of the Phi Beta Kappa in Sanders Theater, Cambridge, Mass., on June 19, 1916. Reprinted from Science, N. S., vol. 44, pp. 37–45, July 14, 1916, and Harvard Graduates' Magazine, vol. 25, pp. 1–10, Sept., 1916.

verse. They speculated intelligently, although often with childlike naïveté, concerning energy and the structure of matter, but they forebore to test their speculations by experiment. They builded better than they knew; their ancient atomic hypothesis, ardently supported but inadequately applied two thousand years ago, now finds itself installed in the innermost recesses of chemical theory. Independently, ancient artisans and medieval alchemists, dealing with the mysterious actual behavior of things, acquired valuable acquaintance with simple chemical processes. After much chemical knowledge of facts had been gained alchemy sought the aid of philosophy. Thus little by little order was brought into the chaos of scattered experience. But strictly chemical knowledge alone was inadequate to solve the cosmic riddle; it had to be supplemented by knowledge of heat and electricity—agencies which produce profound alterations in the chemical nature of substances. Thus the study of physics was combined with that of chemistry. Again, since mathematical generalization is essential to the study of physics, this discipline also was of necessity added to the others. All these powerful tools taken together having failed to penetrate to the ultimate essence of things, imagination is invoked, and physiochemical dreams to-day conceive a mechanism of infinitesimal entities far beyond our most searching powers of direct observation.

Chemistry has not grown spontaneously to its present estate; it is a product of human mentality. The science which we know to-day is but an echo of the eternal and incomprehensible "music of the spheres" as heard and recorded by the minds of individual men. Impersonal and objective although matter and energy may be, their appreciation by man involves much that is subjective. The history of science, like all the rest of human history, is, as Emerson said, "the biography of a few stout and earnest persons."

Robert Boyle, self-styled "the skeptical chymist," a gentle spirit skeptical only of the false and vain, pure-minded aristocrat in an age of corruption; Mikhail Lomonosoff, poet, philosopher, philologist, and scientific seer, far outstripping contemporary understanding; Antoine Lavoisier, whose clear mind first taught man to comprehend, after thousands of years, the mighty stolen gift of Prometheus; John Dalton, Quaker peasant, who found convincing chemical evidence for the ancient atomic hypothesis; Michael Faraday, a blacksmith's son, whose peerless insight and extraordinary genius in experiment yielded theoretical and practical fruits beyond the world's most daring dreams—these men and a few score others are the basis of the history of chemistry. The science has not come into being, Minerva-like, full-grown from the brain of Jove; she has been born of human travail, nursed and nourished from feeble in-

fancy by human caretakers, and she sees the universe to-day through human eyes.

The diversified origin of chemistry has shaped the varied contemporary application of the science and its many-sided destiny in the years to come. Chemistry has wide theoretical bearings, but at the same time is concerned with the crudest and most obvious affairs of manufacture and everyday life. Chemical knowledge must form an essential part of any intelligent philosophy of the nature of the universe, and alone can satisfy one manifestation of that intense intellectual curiosity which to-day, no less than of old, yearns to understand more of the fundamental nature of things. On the other hand, rational applied science to-day must follow in the footsteps of the swiftly advancing strides of theory. The laws of chemistry can not be adequately applied until they have been discovered. Chemical insight, concerned with the intimate changes of the substances which are all about us as well as within our bodies, furnishes us with the only means for employing material things to the best advantage. Chemical processes appertain in large degree to medicine, hygiene, agriculture, and manufacture; these processes depend upon laws of which the perfect understanding is essential to the full development of most of the activities of civilized life.

However oblivious we may be of the inexorable laws of chemistry, we are ever under their sway. Our consciousness is housed in a mortal shell, consisting primarily of compounds of less than a score of chemical elements. The physiological behavior of our bodies is inevitably associated with the chemical changes or reactions among highly intricate chemical unions of these few elements. The driving tendency or immediate cause of the reactions which support life is to be found in the chemical affinities and respective concentrations of the several substances. Our bodies are chemical machines, from which we can not escape except by quitting our earthly life. The nature of the chemical elements and their compounds therefore presents one of the most interesting and important of all problems offered to mankind. That the study of chemical problems of life is consistent with the study of man in a biological, a psychological, or a spiritual sense is obvious. To-day the epigram "The proper study of mankind is man" must be greatly broadened in order to correspond with modern knowledge.

These words regarding the origin and significance of chemistry serve as an introduction. Your committee has honored me by the request that I should tell you something about the object and outcome of my own endeavors, and these could be made clear only by reviewing the peculiar nature of chemistry. In my case the incentive to the pursuit of science was primarily that intense curiosity

concerning the nature of things which echoes down the ages from the time of the ancient philosophers. To the feeling of curiosity, as time went on, was added the perception that only through a knowledge of the fundamental laws of chemistry can men use the resources of the world to the best advantage. Any further gain in this knowledge must, sooner or later, directly or indirectly, give mankind more power. Even an abstract chemical generalization must ultimately be of priceless service to humanity, because of the extraordinarily intimate relation between theory and practice.

The field is wide and it is traversed by many paths. Among these one must be chosen and persistently followed if progress is to be made; and in my case that one was the study of the fundamental attributes or properties of the chemical elements and the relation of these properties to one another. The work was undertaken with the hope of helping a little to lay a solid foundation for our understanding of the human environment.

What, now, are the fundamental attributes of the elements? First and foremost among these stands *weight*—the manifestation of the all-pervading and mysterious force of gravitation possessed by all forms of matter. Hand in hand with this attribute of weight goes the equally inscrutable property of inertia—that tendency which causes a body once in motion to keep on moving forever in the same straight line, if not acted upon by some new force. The idea of inertia, conceived by Galileo and amplified by Newton, was one of the starting points of both modern philosophy and modern physics. So far as we know weight and inertia run parallel to each other. Of any two adjacent bodies, that having greater weight has also greater inertia. Hence they may be determined at one and the same time, and this Siamese-twinlike conjunction of properties establishes itself at once as perhaps the most fundamental of all the attributes of matter. Next perhaps comes volume, the attribute which enables matter to occupy space, with the corollaries dealing with the changes of volume caused by changes of temperature and pressure. Other fundamental properties are the tendency to cohere (which has to do with the freezing and boiling points of the liquids) and the mutual tendency of the elements to combine, almost infinite in its diversity, which may be measured by the energy changes manifesting themselves during the reaction of one substance with another.

These are only a few of the important properties of the elements, but they present an endless prospect of further investigation, in spite of all that has been done during the past hundred years. For as yet we know only the surface of these things, and comprehend but little as to the underlying connections between them and the reasons for their several magnitudes. Why, for example, should oxygen be a gas, having an atomic weight just four times as great as that of

helium, and why should it have an intense affinity for sodium and no affinity whatever for argon or fluorine? No man can answer these questions; he can discover the facts, but can not yet account for them. The reasons are as obscure and elusive as the mechanism of gravitation. But we shall not really understand the material basis upon which our life is built until we have found answers to questions of this sort.

In order to correlate the properties of the elements, and to attain any comprehension of their significance, one must first exactly ascertain the facts. Therefore, my endeavor has been to institute systematic series of experiments to fill the gaps in our knowledge of the actual phenomena. In much of this work I have had the invaluable aid of efficient collaborators, for which I am grateful.

The atomic weights were the first of the fundamental properties of the elements to receive attention in carrying out this plan. These, as everyone who has studied elementary chemistry knows, represent the relative weights in which substances combine with one another. They are called atomic weights rather than merely combining proportions, because they can be explained satisfactorily only by the assumption of definite particles which remain indivisible during chemical change. Even if some of these particles or so-called "atoms" suffer disintegration in the mysterious processes of radioactive transformation, the atomic theory remains the best interpretation of the weight-relations of all ordinary chemical reaction. Indeed, it is entrenched to-day as never before in man's history.

The determination of atomic weights is primarily a question of analytical chemistry—a question of weighing the amount of one substance combined with another in a definite compound—but its successful prosecution involves a much wider field. First, the substances must be prepared and weighed in the pure state, and, next, they must be subjected to suitable reactions and again weighed with proof that in the process nothing has been lost and nothing accidentally garnered into the material to be placed on the scale pan. These requirements involve many of the principles of the new physical chemistry, so that the accurate determination of atomic weights really belongs as much in that field as in the field of analytical chemistry.

At Harvard during the last thirty years the values of the atomic weights of thirty of the most frequently occurring among the eighty or more chemical elements have been redetermined. From data secured here and elsewhere is compiled an international table of atomic weights, revised from year to year by an authoritative committee composed of representatives of various nations. The values thus recorded are in daily use in every chemical laboratory throughout the world, serving as the basis for the computation of count-

less analyses performed by the analytical chemist, whether for technical or for scientific purposes.

This practical utility of atomic weights, although not forgotten, was not the prime incentive in the work under discussion. The real inspiration leading to the protracted labor of revising these fundamental quantities was the hope of finding some clue as to the reasons for their several magnitudes and for the manifest but incomprehensible relationships of the elements to one another.

The unsolved cosmic riddle of the meaning of the atomic weights may have far-reaching significance in another direction, because the atomic weights may be supposed to hold one of the keys to the discovery of the mechanism of gravitation. The mutual attraction of the earth and sun, for example, must be due to the countless myriads of atoms which compose them, each atom possessing, because of its own appointed relative atomic weight, a definite if infinitesimal gravitational force attracting other atoms. If we could discover the reasons for the individual atomic weights we should probably gain a far better understanding of the all-embracing force built up of the infinitesimal effects represented by their individual magnitudes.

Among the striking facts to be considered is the constancy of gravity (and therefore of the sum total of the weights of all the atoms concerned) as shown in many ways. Moreover, not only is the sum total of the weights of the atoms remarkably constant, but also in many cases the values for the individual elements are found to be numbers of amazing constancy. Silver from all parts of the world and from many different ores yields always the same value; copper from Europe has the same atomic weight as the native metal mined under the bottom of Lake Superior; and yet more wonderful, the iron which falls from the sky in meteorites having their birth far beyond the terrestrial orbit has precisely the same atomic weight as that smelted in Norway. Many atomic weights therefore must be supposed to be constant, whatever the source of the elements.

Although thus we know only one kind of copper and iron and silver, evidence has recently been discovered which points toward the existence of at least two kinds of metallic lead. Every sample of ordinary lead always has exactly the same atomic weight as every other sample; but lead from radioactive minerals—lead which seems to have come from the decomposition of radium—has neither the same atomic weight nor the same density as ordinary lead, although in many properties, including their spectra, they seem to be identical. This recent conclusion, reached only two years ago at Harvard, has been confirmed in other laboratories, and it now seems to be beyond question. Whatever may be the ultimate interpretation of the anomaly, the solution of this cosmic conundrum must surely give us a new idea of the essential nature of matter. Indeed, the

fascinating subject of radioactivity bids fair to give us in many ways an entirely new insight into the innermost structure of the atom.

During the progress of the study of the combining proportions of the elements, it became more and more evident to me that the atomic weights should be considered not only in relation to one another but also in relation to many other essential distinguishing properties of the elements. This wider problem involved a great extension of the experimental field.

Among other attributes of the various forms of matter, compressibilities, surface tensions, densities, dielectric constants, heats of reaction, and electromotive forces have begun to receive attention, and already many new data have been accumulated. The explanation of the nature of these researches would take us far beyond the scope of this present address, but their object deserves attention. This object is the correlation of the various properties into a consistent whole, in the hope of tracing the unknown physical influences which determine the nature of the elements.

The rigorous science of thermodynamics enables us to predict in logical and precise fashion some of the relations between physical properties. My hope is not only to aid in providing accurate experimental basis for calculations of this kind, but also to achieve the correlation of different properties, apparently independent of one another from a thermodynamic point of view, thus, perhaps, enabling one by inductive reasoning to penetrate further into the causes which lie back of all the attributes of matter.

In attempting to follow this inductive path comparisons of the properties of the elements have been made in two different ways.

On the one hand, a given property of one element has been compared with the same property of another. For example, the question, "Which of the two elements, cobalt or nickel, has the heavier atom?" was answered by parallel determinations, using the same methods, conducted side by side in the laboratory. Cobalt was found to possess the higher atomic weight.

On the other hand, the attempt has been made to discover a relation between the different, apparently quite distinct, properties of a single element. For example, one may ask: "Have the low melting and boiling points of phosphorus any connection with its small density and its large compressibility?" Here one compares various properties of the same element, and one seeks to discover if all are based upon some common, ultimate characteristic of phosphorus, of which the properties are merely symptoms.

The inductive methods used in comparisons of this sort can not be explained here. They are partly statistical, partly mathematical,

and partly graphical. From the nature of the problem, which involves many unknown variables, perfect mathematical exactness is not to be expected. Nevertheless, little by little, one may hope to trace the conflicting tendencies and ascribe them to a few common causes.

With the help of these methods the tentative conclusion has been reached that the space occupied by the atom and molecule in solids and liquids is highly significant. The actual atomic bulk or volume is diminished but slightly by moderate mechanical pressures and by cooling even to the absolute zero; but it is very greatly affected, apparently, by the mutual attractions of the atoms, called cohesion and chemical affinity. Usually the less volatile a substance (that is to say, the more firmly it is held together by cohesion) the greater is its density and the less is its compressibility, other things being equal. Greater cohesion is associated with greater compactness. Likewise, the existence of powerful chemical affinity between elements forming a compound is usually associated with great decrease in volume during the act of combination, and consequent increase in the density of the product in relation to the average density of the constituents. Thus, we can hardly escape the inference that both cohesion and affinity, by pulling the atoms together with enormous pressure, actually exert a compressing effect upon the atoms, or at least upon the space which they demand for their occupation. The result of each of these compressing agencies is found to be greater the greater the compressibility of the substances concerned— a new evidence of the reasonableness of the inference. Not always are these effects easily traced, because the situation is often complicated, and the several effects are superposed. Nevertheless, enough evidence has been obtained to leave but little doubt, at least in my mind, as to the manner of working of the essential agencies concerned.

But we need not dwell upon this tentative hypothesis. Many more data and much more thought are necessary to establish it in an impregnable position, although no important inconsistency has thus far been pointed out in it. At present it may be looked upon as valuable because it, like other hypotheses of this type, has stimulated thought and experiment concerning the fundamental facts with which it deals.

As the years go on, the recent contributions to the study of atomic weights and volumes and other properties will be sifted and tested; and such contributions as may stand the test of time will take their places among the multifarious array of accepted chemical facts, laws, and interpretations accumulated by many workers all over the world.

But we may well ask: What use in the years to come will mankind make of this knowledge gained step by step through the eager study of many investigators?

Chemistry has, indeed, a many-sided destiny. A mere catalogue of the countless applications of the science, which underlies many other sciences and arts, would demand time far exceeding the limits of this brief discourse. Some of the more obvious uses of chemistry have become daily topics in the public press. America is gradually awakening to the consciousness that, because every material object is composed of chemical elements and possesses its properties by virtue of the nature of these elements, chemistry enters more or less into everything. We perceive that chemical manufactures must be fostered, and also that chemical knowledge must be applied in many other industries not primarily of a chemical nature. Although chemistry plays so prominent and ghastly a rôle in war, her greatest and most significant contributions are toward the arts of peace. Even explosives may be highly beneficent; they may open tunnels and destroy reefs, furthering friendly communication between men; dig ditches for irrigation; help the farmer in his planting; and in many other ways advance the constructive activities of mankind. Again, poisonous gases, confined and harnessed within safe limits, may render valuable aid to humanity in preparing precious substances otherwise unattainable.

Such obvious and well-recognized offices of chemistry need no further presentation to this intelligent company. Neither is it necessary for me to call your attention to the services which science may render to agriculture through the chemical study and enrichment of the soil in preparing it for the development of those subtle chemical mechanisms called plants, upon which we depend for our very existence.

There is a further beneficent possibility worthy of more than passing mention—namely, that which arises from the relation of modern chemistry to hygiene and medicine. Already your attention has been called to the indisputable fact that the human body is, physiologically considered, a chemical machine. For this reason, future knowledge of chemical structure and of organic reaction may perhaps revolutionize medicine as completely as it was revolutionized by the devoted labors of Pasteur—not by doing away with his priceless acquisitions of knowledge, but rather by amplifying them. Chemistry may show how germs of disease do their deadly work through the production of subtle organic poisons, and how these poisons may be combated by antitoxins; for both poisons and antitoxins are complex chemical substances of a nature not beyond the possible reach of chemical methods already known. In that far-off

but not inconceivable day when the human body may be understood from a chemical standpoint we shall no longer be unable to solve the inscrutable problems which to-day puzzle even the most learned hygienist and physician. Is not a part, at least, of the tragedy of disease a relic of barbarism? A race which could have put as much energy and ingenuity into the study of physiological chemistry as mankind has put into aggressive warfare might have long ago banished many diseases by discovering the chemical abnormalities which cause them.

May not the study of subtler questions, such as the nature of heredity, also lead us finally into the field of chemistry in our search for the ultimate answer? Even psychology may some time need chemical assistance, since the process of thinking and the transmission of nervous impulse are both inextricably associated with chemical changes in nervous tissue; and even memory may be due to some subtle chemical effect. In the realm of thought there can be no question of the blessed service already performed by science in dispelling grim superstitions which haunted older generations with deadly fear.

In brief, more power is given mankind through the discoveries of chemistry. This power has many beneficent possibilities, but it may be used for ill as well as for good. Science has recently been blamed by superficial critics, but she is not at fault if her great potentialities are distorted to serve malignant ends. Is not this calamity due rather to the fact that the spiritual enlightenment of humanity has not kept pace with the progress of science? The study of nature can lead an upright and humane civilization ever higher and higher to greater health and comfort and a sounder philosophy, but that same study can teach the ruthless and selfish how to destroy more efficiently than to create. The false attitude toward war, fostered by tradition and by the glamor of ancient strife, is doubtless one of the influences which have held back mankind from a wider application of the Golden Rule.

There is, in truth, no conflict between the ideals of science and other high ideals of human life. With deep insight, a poetic thinker on life's problems, in the opening lines of a sonnet, has said:

> Fear not to go where fearless Science leads,
> Who holds the keys of God. What reigning light
> Thine eyes discern in that surrounding night
> Whence we have come, . . .
> Thy soul will never find that Wrong is Right.

Our limited minds are confined in a limited world, with immeasurable space on all sides of us. Our brief days are as nothing compared with the inconceivable æons of the past and the prospect of illimitable ages to come. Both infinity and eternity are beyond our

mental grasp. We know that we can not hope to understand all the wonders of the universe; but, nevertheless, we may be full of hope for the future. Step by step we gain in knowledge, and with each step we acquire better opportunity for improving the lot of mankind and for illuminating the dark places in our philosophy of nature. Although we shall none of us live to see the full development of the help which science may render to the world, we rejoice in the belief that chemistry has boundless service still in reserve for the good of the human race.

THE EARTH: ITS FIGURE, DIMENSIONS, AND THE CONSTITUTION OF ITS INTERIOR.[1]

By T. C. Chamberlin, Harry Fielding Reid, John F. Hayford, and Frank Schlesinger.

I.

THE INTERIOR OF THE EARTH FROM THE VIEWPOINT OF GEOLOGY.

By T. C. Chamberlin.

For some time past there has been a marked drift of geologic opinion from the older tenet of a molten earth toward the conviction that the earth is essentially solid. This trend has been quite as much due to the contributions of kindred sciences as to the growth of geologic evidence, but geology has made its important and concurrent contributions to it.

The great granitic embossments that constitute the most distinctive feature of the oldest known terranes were formerly regarded as solidified portions of a primitive molten earth and thus seemed to serve as witnesses to the verity of the former liquid state. A few years ago, however, it was determined—almost simultaneously in several countries where critical studies on these formations were in progress—that these granitic masses are intrusive in older formations that had previously been formed *at the surface of the earth*. These surface formations have thus come to stand as the most ancient terranes now known. These earliest accessible deposits imply the preexistence of a suitable foundation formed at a still earlier date. Neither the surface sediments nor the intrusives give any clear intimation that formations beneath them are different in origin from themselves. So far, then, as the record runs, it testifies to substantial solidity in the outer part of the globe.

The record implies, indeed, that some molten matter was present, but gives no certain measure of the ratio of the molten to the solid part. At no stage covered by the lithographic record, indeed, is there

[1] Reprinted, by permission, from Proceedings of the American Philosophical Society, September and October–December, 1915.

determinate evidence that a molten condition was preponderant even in the interior. The interior conditions of the earliest as well as the later stages are to be reached only by indirect rather than immediate inference. Under the influence of inherited presumptions, it may seem to many still probable that the interior of the mature earth was once dominated by a molten condition at some remote stage, but the evidence of powerful inthrusting of the igneous element into even the earliest terranes, so often shown in the oldest intrusions, seems to imply that the molten element was ever in the strong grasp of stresses of the type normal to a rigid globe. This harmonizes with the belief that the liquid matter was then only a minor and passive factor, not a controlling one.

If the earth were once wholly molten, the material for all the stratified rocks of later ages must have been derived from the primitive crust after it was formed and forced into positions of erosion, or else from matter extruded through it. This primitive feeding ground should, it would seem, be a notable feature on the geological map. The absence, according to present knowledge, of any great area of rocks bearing the distinctive characteristics of the supposed congealed surface greatly weakens the assumption that the postulated molten state ever obtained, at least in the mature earth.

A study of the stress conditions of the interior of the earth seems to call for a similar reversal of the inferences once drawn from the igneous rocks. From the earliest well-recorded ages, the exterior of the earth has given evidence of broad topographic reliefs taking the form of great embossments and broad basins. These surface configurations must have conditioned the localization of extrusions and the deployment of the effusive material. If the lavas arose from a general and abundant source of supply which was responsive to general and powerful stresses, vestiges of these conditions should be found in vast volumes and broad deployments of the lava floods. If, on the other hand, the molten material formed but a fraction of the whole mass, and was variously distributed through it, the result should be a multitude of driblets squeezed out here and there in such special situations as the controlling stresses required, or else a multitude of limited intrusions forced into weak portions of the earth body where the stresses were less imperative. The latter rather than the former seems to accord with the testimony of the record.

Now there is abundant geological evidence that the earth body has been subjected at repeated intervals to strong compressive stresses, by which its outer portion has been folded into mountainous ranges or pushed up into great plateaus, while masses of continental dimensions have been raised, relatively, to notable heights, and the bottoms of basins and deeps have sunk reciprocally to even greater relative depths. The internal stresses which these deforma-

tions imply should have made themselves felt proportionately on any great mass of liquid in the interior, if it were in existence, and extrusions proportionate to the greatness of the deformations should have accompanied such diastrophism. But, while liquid extrusions took place somewhat freely at the times of great diastrophism, it was not, at least in my judgment, at all commensurate with the deformative stresses implied by the diastrophic results shown in the solid material.

Nor was the topographical concentration of the extrusions indicative of their origin from a molten interior or from really great residual reservoirs of liquid rock. If such ample sources of liquid had existed, they might naturally have been expected to have given forth, under the great stresses then seeking easement, correspondingly great floods of lava which would have gone far to fill the great basins into which they must chiefly have flowed. Yet no single lava flood seems to have attained more than an extremely small fraction of the mass of the earth, or even of the known solid matter of the immediate region of the outflow. Even when the sum total of the most massive series of successive floods in a given region are taken together—though the successive issues stretched over a considerable period—they rarely rise above a most insignificant fraction of earth mass, or even of the regional segment of it with which they are associated. Instead of really massive flows, implying ample sources of supply and great forces of extrusion, the record shows rather a multitude of little ejections or injections of more or less sporadic distribution. The logical implication of these is the preexistence of a multitude of small liquid spots, or liquifiable spots, scattered widely through the stressed earth masses and yielding to stress as local conditions required and where local conditions required.

This inference is pointedly supported by the great variations in altitude at which lavas are now given forth and seem to have always been given forth so far as the record goes. The most impressive illustrations of this are found in current volcanic action where the relations in altitude are precisely known. So far as ancient conditions can be restored, they appear to fall into the same general class as existing conditions. Current outpourings of lava range from the sea bottom to altitudes of many thousands of feet above sea level, a vertical range of several miles. Extrusions occur at these significantly diverse altitudes simultaneously or alternately or in almost any time relations, and sometimes in the most marked independence of one another, in spite of the natural sympathy which such events might naturally manifest in a common stressed body. A multitude of facts of detail, some of which are singularly cogent, imply that the lava sources of present volcanoes are disconnected from one another in the interior, and are hence independent in action, as a rule,

though sometimes they show sympathy without showing evidence of liquid connection. The sources of lava seem to be meager in general, and the eruptive agencies seem to be controlled by narrowly local conditions. There is an absence of evidence that the lavas in the craters or in the necks of volcanoes are parts of great liquid masses below, responsive to the common stresses of a large region.

Thus geological evidence, when critically scrutinized, seems to be distinctly adverse to the existence of even large reservoirs of molten matter within the earth; it points rather to the presence of scattered spots, very small relatively, on the verge of liquefaction, which pass by stages into the liquid form and are then forced out by the differential stresses that abound in the earth body, or are embodied in the liquid itself, each such local liquefying center commonly giving forth driblets of lava and gas at intervals, none of which often rise to more than an extremely minute fraction of the earth mass or even of the subterranean mass contiguous to the volcano.

A revised view of the nature and location of earth stresses seems also to be required by what is now know of earth conditions. Under the former dominance of the tenet of a molten globe it was natural to assign to the stress differences of the earth a distinctly superficial localization and limitation; they were thought to be affections of "the crust" almost solely. Hydrostatic pressures were of course recognized as affecting the deep interior, but these were obviously balanced stresses, and were ineffective in deformation. The stresses supposed to give rise to the great reliefs of the earth's surface were thought to be very superficial. But the stresses imposed by known deformative agencies are not all superficial, nor are their intensities always greatest at the surface. According to Sir George Darwin, the stress differences generated in the earth by the tidal forces of the moon are from three to eight times as great at the center of the earth as at the surface. So, also, according to the same authority, the stresses engendered by changes in the rotation of the earth are from three to eight times as great at the center as at the surface and are graded between center and surface. The tidal stress differences are relatively feeble but are perpetually renewed in pulsatory fashion. Those that arise from rotation belong to the highest order of competency. The stress difference that would arise at the center of the earth from a stoppage of the earth's rotation would, according to Darwin, reach 32 tons per square inch. Changes of the rate of rotation are almost inevitable when great diastrophic readjustments take place. Such periods are to be regarded as critical times at which great floods of lava should be poured forth from the interior if liquid material were there in great volume ready to respond to the changes of capacity which the deformations of the earth's sectors and the changes in the spheroidal form would inevitably impose.

Not to detain you with other considerations, the foregoing seem best to comport with an essentially solid state of the earth's interior, if they do not point rather definitely to such a state. Even if they stood alone, they would seem to make a prevailing solid state the most tenable working hypothesis.

But they are far from standing alone; the geological evidences are strongly supported by considerations that spring from several kindred lines of inquiry. The testimony of astronomic evidence is given below by Dr. Schlesinger. The import of seismic studies, the subject of Dr. Reid's contribution, lends very special support to the view that the interior of the earth is elastico-rigid at least to the extent that distortional waves pass through its interior. It seems certain already that this condition prevails throughout much more than half the volume of the earth; concerning the rest, the deep interior, the seismic evidence is perhaps still to be regarded as indeterminate. But on the seismic evidence it does not fall to me to dwell.

The tidal studies of Hecker, Orloff, and others lend support to the tenet of a rigid earth but they fall somewhat short of conclusiveness. The brilliant experimental determinations of Michelson and Gale, correlated with the computations of Moulton, have carried the evidence to the point of preliminary demonstration. They need only to be adequately repeated and verified to become final, so far at least as elastic rigidity can be indicated by the response of the earth body to solar and lunar attractions. The special feature of most critical value in the demonstrations of Michelson and his colleagues is the high degree of elasticity shown by the almost instantaneous response of the earth to the distorting pull of the tide-producing bodies. This cuts at the very base of concepts founded on the supposed properties of a viscous earth. These tidal determinations of elasticity are in close accord with the seismic evidences. The two are happily complementary to one another. The one deals with the earth as a whole under a rhythmical series of increasing and diminishing stress differences springing from external attractions; the other deals in an intensive vibratory way with earth substance by sharp short stresses that call into action its most intimate structural qualities. While it is wise, no doubt, to refrain from resting too much on these early results of relatively new and radical lines of inquiry, until their results shall be more mature, their prospective import is radical and decisive in favor of a solid earth not only, but of an elastico-rigid earth. Assuming that the present import of these inquiries will be amply justified by more mature research, it is pertinent to bring into consideration the corollary they so distinctly imply, viz, that the molten and viscous material in the earth, or at least in its outer half, if not throughout its deep interior, is a negligible factor in general studies, and enters

into general terrestrial mechanics only as a subsidiary feature. It seems necessary to limit liquid and viscous lacunæ—if there are lacunæ in any proper sense at all—to such moderate dimensions that they do not seriously kill out distortional waves passing through the outer half of the globe in various directions, for seismic instruments show that these waves retain their integrity with surprising tenacity through long traverses. It seems equally necessary to limit the liquid and viscous factor rather severely if the interior structure is to be susceptible of so prompt a response to twelve-hour stress pulses as is implied by its almost complete elastic fidelity.

In the light of these determinations, strengthened not a little by their concurrence with the later geological determinations, the working hypotheses of the earth student can scarcely fail to take shape according to the dynamic tenets implied by a rigid earth.

The limitation of liquid and viscous matter thus imposed quite radically conditions all tenable views of magmas and of vulcanism, and thus bears upon the origin of igneous matter. No small part of petrologic effort in past decades has been spent on the differentiation of magmas. To a notable degree these efforts have proceeded on the assumption, conscious or unconscious, that differentiation took its departure from an original homogeneous magma such as might arise from residual portions of a molten earth. Indefinite lapses of time, and such conditions of quiescence as are naturally assignable to residual reservoirs of lava, have been freely assumed as working conditions without much question as to their reality. Under the hypothesis of a molten earth passing slowly into a partially solid earth and retaining residual lacunæ of molten matter as an incident of the change, these assumptions are quite natural. On the other hand, under the hypothesis of a pervasively rigid earth, affected by stress conditions that are constantly varying in intensity and in distribution—and subject to more radical changes at times of periodic readjustment—the existence of such residual magmas becomes at least questionable, perhaps improbable. Still more questionable is the assumption that the multitude of little liquid spots supposed to arise within the elastico-rigid mass always have conformed to one type or to one set of types. The inherent probabilities of the case seem to point strongly to a wide variation in nature of these local bodies due to selective solution or to differential fusion. The liquefying action that brings magmas into being under this view is presumably controlled by the same chemical and physical principles as the solidifying phases of the same cycle. The logical presumption is that at all stages of a magma's career from its inception through its growth, climax, and decline to its final solidification, selective action will be in progress more or less and that no stage will be entitled to be regarded as original or parental in a special sense, such a sense, for

example, as might be appropriate if the lava were the residue of an inherited original state and were merely differentiated by fractional crystallization as it passed toward solidification.

While these contrasted views of the history of magmas are naturally connected with views of the genesis of the earth, they are not limited to this connection. They are inherent in the very relations of solid and liquid matter; they have a more or less important place irrespective of the earth's genesis; they would raise even keener questions than they do if the earth were supposed never to have had a genesis, but to have always existed.

An element of no small importance to a revised concept of the interior of the earth has arisen from geodetic studies on the distribution of densities within the earth. As the geodetic point of view is to be presented by its foremost exponent, Dr. Hayford, it is permissible for me merely to refer to certain geologic bearings.

On the assumption that the earth was once in a molten state, the inference is unavoidable that a perfect state of isostatic equilibrium was originally assumed by the surface, and that its primitive configuration was strictly spheroidal. The material must have been arranged in concentric layers according to specific gravity, and each layer should have had the same density at every point. All such reliefs of the earth's surface as have since arisen as well as all such differences of specific gravity as now exist in the same horizon must have been superinduced upon this originally perfect isostatic state. With good reason therefore these inequalities have heretofore been supposed to be relatively shallow. It is difficult to account for them, then, even hypothetically. On the hypothesis that the earth grew up by heterogeneous accretions, it is an equally natural inference that differences of specific gravity extend to great depths. In an endeavor to find out the bearings of geodetic data on the distribution of densities, Dr. Hayford tested four assumptions, all of which he found measurably compatible with his geodetic data. From these he derived the respective compensation depths of 37, 76, 109, and 179 miles, these being the horizons to which differences of density extended and below which they vanished or became negligible. Now all these depths are notably greater than had been assigned as probable depths of differentiation in the traditional molten earth. On the other hand, the highest figure, 179 miles, was derived from a curve drawn specifically to represent the probable distribution of densities in an earth of planetesimal growth. The distribution represented by this highest figure fits the geodetic data quite as well as either of the other assumptions of distribution, though drawn on a strictly naturalistic basis. If it could be said that geodetic data demonstrate that the actual differentiation of specific gravities extends to depths of

the order named, such considerable depths would distinctly favor an accretionary origin as against a molten origin. But the determination is inconclusive.

While it is possible, within the broad terms of the planetesimal hypothesis, to suppose that the rate of accretion was so fast as to give rise to a molten planet, such a result seems to me extremely improbable under the actual conditions of the case. The growing planet should have become capable of holding a considerable atmosphere by the time it attained one-tenth of its present mass, i. e., about the mass of Mars. After this the protective cushion of the atmosphere should have greatly checked the plunge of the planetesimals and thus have largely dissipated them into dust in the upper atmosphere where the inevitable heat of impact would be promptly radiated away. The dust presumably floated long and came gently to earth, so that, while the total heat generated by impact was large, the mean temperature of the earth body was probably never above the local solution or fusion point of the more refractory material during the later stages of growth, and perhaps not at any stage of growth. Following out as well as may be the probable rates and conditions of growth, the most tenable concept of the state of the earth's interior under the planetesimal hypothesis is as follows:

The condition of the nuclear portion supposed to be formed from one of the knots of the parent spiral nebula and constituting a minor fraction of the mass of the earth, say 30 or 40 per cent, is left indeterminate by present lack of knowledge of the physical state of the knots of spiral nebulæ. If these are gaseous—which is rendered doubtful by their lack of strict sphericity—the nucleus was doubtless originally molten. If the constituents of the knot were held in orbital relations, their aggregation might have been slow enough to permit a solid state of even this portion. The matter added to the nucleus as planetesimal dust, or as planetesimals reduced in mass and speed by the atmosphere, probably retained its solid condition, with negligible exceptions, throughout the process of accretion, except as selected portions passed into the liquid state and became subject to extrusive action. An intimate heterogeneity naturally prevailed throughout the whole mass so aggregated. A selective process, however, probably brought in the heavier matter faster and earlier than the lighter matter, for the magnetism of the earth should have aided gravity in gathering in the magnetic metals, while the inelastic planetesimals, predominantly the heavy basic ones, when in collision destroyed the opposing components of their motions and hence yielded to the earth's gravity sooner than the more elastic ones. Relatively high specific gravity in the material of the deep interior is thus thought to have arisen at the outset and to have been increased by the selective vulcanism that came into action

as growth proceeded. Special emphasis is laid on the *selective* nature of vulcanism under this hypothesis. The intimate mixture of planetesimals and planetesimal dust gave rise to a multitude of minute contacts between particles of different chemical and physical properties, and hence there arose wide differences in the solution points. As the temperature in the growing planet rose, the more soluble portions passed into the liquid state by stages long before the remaining larger portion reached the temperature of solution. In a stressed globe certain of whose stresses are more intense toward the center than toward the surface, the solutions were forced to work in the direction of least resistance—for them generally outward—carrying out heat of liquefaction and leaving behind the less soluble larger portion whose temperatures were inadequate for further liquefaction until there was a renewed accession of heat. The mechanism thus automatically tended to remove the most soluble constituents by progressive stages, while it tended to preserve the solid condition of the remaining mass. The hypothesis thus supplies a working mechanism whose results fall into full accord with the states of the interior implied by tidal investigations and by seismic data, while the distribution of specific gravities naturally assignable under it accords well with the best geodetic determination thus far made.

The adaptation of such an earth to isostatic adjustment can scarcely be more than hinted at here. The growth of the earth should have given it a concentric structure, while its highly distributive vulcanism, together with some of its deformative processes, should have given a vertical or radial structure, the two conjoining to give a natural tendency to prismatic or pyramidal divisions converging toward the center. The most powerful of all the deformative agencies—rotation—required for the adaptation of the earth to its changes of rate such divisions of the earth body as would respond most readily to depression in the polar and bulging in the equatorial tracts reciprocally or their opposites. As urged elsewhere, this accommodation seems best met by three pyramidal sectors in each hemisphere, with apices at the center and bases at the surface, the sectors in opposite hemispheres arranged alternately with one another. Very simple motions within these sectors would satisfy the larger demands of rotational distortion, while the subsectors into which these major sectors would naturally divide, as stresses required, would easily accommodate the nicer phases of adjustment. This primitive segmentation to meet rotational demands—which were most urgent during the stages of infall—furnished a mechanism suitable for the easement also of a portion of the deformational stresses that arose from other sources, among them gravitative stresses arising from loading and unloading by erosion

and sedimentation. A gravitational adjustment by the wedging up and down and laterally of such sectors is thus offered tentatively as a working competitor to theories of adjustment by fluidal or quasi fluidal undertow. The necessary brevity of this statement leaves this new hypothesis little more than a crude suggestion that gravitative adjustment (=isostasy) may perhaps take place as fully as the case requires in a highly rigid elastic earth, affected by vertical schistosity and an adaptability in wedging action, without resort to flowage or even quasi flowage.

II.

CONSTITUTION OF THE INTERIOR OF THE EARTH, AS INDICATED BY SEISMOLOGICAL INVESTIGATIONS.

By Harry Fielding Reid.

In 1883 Milne predicted that earthquake disturbances would be registered by seismographs at great distances from their origin, a prediction first verified when the earthquake of April 18, 1889, whose origin lay off the coast of Japan, affected the horizontal pendulum which von Rebeur-Paschwitz had set up at Potsdam to study the attraction of the moon. Milne was so convinced of the correctness of his idea and of the importance of the results to be obtained that in 1893 he established an observatory on the Isle of Wight to record earthquakes from distant regions; and he also succeeded in having instruments of similar model set up at observatories very widely scattered in various parts of the world.

Wertheim in 1851 showed that a disturbance in the interior of an elastic solid would break up into two groups of waves, longitudinal and transversal, which would be propagated at different rates, and as their velocities are so great that they can not be separated from each other in the laboratory he suggested with rare insight that their separation might first be noticed in connection with the propagation of earthquake disturbances.[1] A few years later Lord Rayleigh showed that a third kind of wave could be propagated along the surface of the earth.[2] Seismologists naturally looked for indications of these three groups of waves in their seismograms, but it was not until 1900 that Oldham succeeded in showing definitely that the seismograms of a number of Milne instruments gave clear evidence of the existence of three groups of waves. Oldham also published a diagram, which was an extension of Seebach's so-called "hodograph," showing the relation between the time of transmission of each group and the distance from the earthquake origin, measured

[1] "Sur la propagation du movement dans les corps solides et liquides," *Ann. de Chimie et Phys.*, 1851, vol. 21, p. 19.

[2] "On Waves Propagated Along the Plane Surface of an Elastic Solid," *Proc. London Math. Soc.*, 1855, vols. 47, 50.

along the surface of the earth. Milne soon improved these curves by adding observations of a large number of recorded shocks.[1] The curves of the first and second "preliminary tremors," as Milne called the first two groups of waves, are curved, indicating that the velocity of transmission increases with the distance from the origin; a conclusion which had already been drawn from earlier, but less accurate, observations. Milne attempted to explain this by assuming that the path of the seismic disturbance lay along the chord and not along the earth's surface; this practically shortens the distance to the observing stations, and if the curves are plotted, with distances measured along the chord, the curvature is considerably diminished; but later and more accurate observations show that even under this assumption the velocity still increases with the distance. The conclusion is unavoidable that as the path of the disturbance sinks deeper into the earth the velocity increases. The interior of the earth then is not a homogeneous but a refractive medium, and the path of the disturbance can not be straight but must be curved with the concavity turned upward. This condition had been described by A. Schmidt as early as 1888.[2] Seismologists now believe that the three groups discovered by Oldham are respectively the longitudinal, the transverse, and the surface waves. The transmission curve of the latter is a straight line indicating that the waves are transmitted with uniform velocity along the surface of the earth. They have affected seismographs after having passed completely around the earth. It can not be said that the evidence, that the first two groups are respectively longitudinal and transverse, is complete; but it is sufficient, in connection with theory, to make seismologists fairly confident that the conclusion is correct; and the passage of transverse waves through the earth to great depths is proof that, to those depths, the earth is solid; for transverse waves can not exsit in a liquid. Further, since the velocity of transmission depends on the ratio of the elasticity to the density of the medium, and since both the longitudinal and transverse waves increase in velocity with the depth below the surface, both the elasticity of volume and the elasticity of figure of the earth, not only increase, but increase more rapidly than the density as we penetrate below the surface. The earth therefore is not only rigid, but its rigidity increases toward its center; though seismological evidence does not yet prove that this characteristic extends to the very center itself.

The next step was to determine the path of the waves in the earth and their velocity at different depths: the data for these determinations were the times of arrival of the earthquake waves at various

[1] Rep. of Com. on Seismol. Investig., B. A. A. S., 1902, p. 7.

[2] "Wellenbewegung und Erdbeben," *Jahreshefte für Vaterlands Naturkunde in Württemberg*, 1888, p. 248.

distances from the origin; these times are collected in the transmission curves. At first sight this seems an insoluble problem; but, thanks to a remarkable mathematical theorem of Abel, it is not. It is clear that the time of arrival of an earthquake disturbance at a distant station will depend on the path followed and the velocity in different parts of the path, and if we make the reasonable assumption, which is borne out by observation, that the velocity is everywhere the same at the same depth, then it is evident, if the velocity increases continuously with the depth, that the transmission curves will be continuous without breaks, and their curvatures will nowhere make a sudden change. The mathematical solution of the problem has been obtained by Wiechert, Bateman, and others; and concrete results have been obtained by Wiechert and his assistants, so that we now know the paths of the waves and their velocities with a fair degree of accuracy, at least to a considerable distance below the surface. But the questions arise, Do the velocities increase continuously with the depth; and if so, How? questions which could be answered by the study of perfect transmission curves; but even imperfect curves yield some information; which, however, may be so faulty that it must be received with great caution. Milne, who has done such excellent pioneer work in seismology, was the first to propose and attempt to answer these questions.[1] He thought the transmission curve could be satisfied by supposing the earth to consist of a solid core having a radius of nineteen twentieths of the earth's radius, and surrounded by a thin shell. The core was of uniform density and elasticity, so that the velocity of propagation in it was uniform, and the paths of the rays would be straight lines. The velocity in the shell was much less than in the core. These conditions satisfied fairly well the very imperfect transmission curve of 1902, but they may be dismissed without further consideration, for such an earth could not satisfy the astronomic requirements, which exact, at the same time, the proper mean density and moment of inertia.

Benndorff in 1906 thought he found evidence of a central core of about four-fifths the earth's radius, surrounded by two shells, the outer one having the same thickness as Milne's.[2] In the same year Oldham deduced from the transmission curves a central core of not more than four-tenths the earth's radius in which the velocity was distinctly less than in the surrounding shell.[3] Neither of these arrangements have been shown to conform to the astronomic requirements. Oldham's conclusions are based on what he considers a

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[1] Rep. of the Com. on Seismol. Investigation, B. A. A. S., 1903, p. 7.

[2] "Ueber die Art der Fortpflanzungsgeschwindigkeit der Erdbebenwellen in Erdinnern," *Mitt. d. Erdbeben Com. k. Akad. Wiss. in Wien*, 1906, Nos. 29 and 31.

[3] Constitution of the Interior of the Earth, *Quart. Jour. Geol. Soc.*, 1906, vol. 62, p. 456.

distinct break in the transmission curve of the transverse waves at distances between 120° and 150° from the origin; but when we remember that fully 95 per cent of the energy of an earthquake shock comes to the surface within the hemisphere having the origin as its pole, we see that the data for great distances must be too imperfect to yield very reliable deductions.

Many years ago Roche showed that it was quite possible to determine a distribution of density in the earth which would be discontinuous at several levels, but which would still be astronomically satisfactory. Weichert, in 1897,[1] showed that such a system might consist of a central core of radius about 4,900 km. or three-fourths of the earth's radius, consisting of iron with a density of about 8.3, surrounded by a stony shell about 1,500 km. thick and with density varying from 3 to 3.4. It was natural that he should examine the transmission curves to see if they supported his ideas; and at The Hague meeting of the International Seismological Association in 1907 he announced that they did. At the Manchester meeting of the same association in 1911 he announced the existence of two shells around the central core. In 1914 Gutenberg (one of Wiechert's assistants) announced the existence of three shells.[2] In addition to ordinary times of transmission, Gutenberg also used the times of waves reflected at the earth's surface and the variations in the amplitude; it is evident that a wave which crosses the boundary of the core will experience reflection and refraction; and whichever part is later observed at the surface of the earth will have a distinctly smaller amplitude than the wave which just missed penetrating into the core. The following table shows the positions of the boundaries of the shells and of the core, and the velocities of the longitudinal waves P and of the transverse waves S; it will be noticed that it is only at the boundary of the central core that any marked sudden change in velocity occurs.

Depth, kilometers.	Velocity, kilometer-seconds.	
	P.	*S.*
0	7.17	4.01
1,200	11.80	6.59
1,700	12.22	6.88
2,450	13.29 13.15	7.34 7.20
2,900	13.15 8.50	7.30 4.72
6,370	11.10	6.15

[1] Ueber die Massenvertheilung im Innern der Erde." *Nachr. k. Gesells. Wiss. Göttingen*, 1897; *Math.-phys. Kl.*, p. 221.

[2] Ueber Erdbebenwellen," VIIA. *Nach. k. Gesells. Wiss. Göttingen; Math.-phys. Kl.*, 1914, p. 1; references to the earlier numbers of the series are given in this paper.

The remark regarding Oldham's results applies also here, namely that it is questionable whether the observations at distances greater than 100° or 120° are sufficiently accurate to justify such definite conclusions. Gutenberg had the advantage, however, of more accurate observations than Oldham, and also of measures of amplitudes. There is no a priori reason why the earth might not be made up of a number of shells, but there should be satisfactory evidence for any proposed system; and it must be shown to satisfy the astronomic requirements; or, at least, not to contradict them. Gutenberg's system does not correspond with Wiechert's system of 1897. In the latter a marked change in physical properties occurs at a depth of 1,500 km.; in the former, at a depth of 2,900 km.; and in crossing into the core, the ratio of the elasticity to the density, according to Gutenberg, rapidly loses six-tenths of its value. This change might be the result of a great increase in density or a great decrease in elasticity; it may be questioned whether the former is compatible with the astronomic requirements, and whether the latter is compatible with the high rigidity which we know the earth, as a whole, has. So far no answer has been given to these questions.

In 1879 George and Horace Darwin attempted to determine the rigidity of the earth by measuring the deviation of the vertical under the attraction of the moon. If the earth yielded like a fluid, its surface would always remain at right angles to the vertical, and a pendulum would remain relatively stationary for all positions of the moon; if the earth were absolutely rigid, the moon's attraction would deflect the pendulum an extremely small amount, but an amount capable of being measured. The Darwins did not obtain definite results because the disturbances of their pendulum were greater than the deflections they attempted to determine.

A little later von Rebeur-Paschwitz attacked the same problem with better success, using a horizontal pendulum.

Hecker, in Potsdam, and Orloff, in Dorpat, have repeated von Rebeur-Paschwitz's experiment; and both found values for the average rigidity of the earth comparable with that of steel. But, what was most remarkable, and what is still unexplained, the rigidity was apparently greater in an east-west than in a north-south direction. Orloff, experimenting at a greater distance from the ocean, found a smaller difference than Hecker did, and it has been suggested that the tides of the ocean are the cause of the difference. The International Seismological Association, at its Manchester meeting in 1911, made plans to repeat the experiments in Paris, in central Canada, in the middle of Southern Africa, and in the middle of Russia; but no reports have yet come from these stations.

In the autumn of 1913 Michelson attacked the same problem by a new method, which seems capable of yielding more accurate

results than the horizontal pendulum. He measured the deflection of the vertical under the influence of the moon by what was practically a water level 500 feet long, sunk 6 feet in the earth.[1] Michelson's results for the east-west rigidity do not differ greatly from those of Orloff; but his north-south rigidity is somewhat less than Orloff's. Michelson's experiments also show that the viscosity of the earth must be as great as that of steel. These experiments are of great interest; they should be repeated at various places, and especially at places symmetrically situated with respect to the great oceans, and on midoceanic islands, in order to determine how far they are affected by the oceanic tides.

We can say in conclusion that the transmission of transverse earthquake waves shows that the earth is solid, at least to a great depth below the surface; and that experiments on the deflection of the vertical show that it is quite as rigid and as viscous as steel. There are still difficulties in the interpretation of the observations, but their elucidation can not alter the general character of the conclusions.

III.

THE EARTH FROM THE GEOPHYSICAL STANDPOINT.

By John F. Hayford.

This is a broad topic on which much intensive thinking has been done by many men. It is impossible to treat it adequately or comprehensively in the short time available.

In this address an attempt will be made to so concentrate attention on a certain few points as to tend to clarify existing ideas and to correlate them. An attempt will also be made to help in locating the lines of least resistance to future progress in the study of the earth.

The size of the earth, as well as its shape, is now known with such a high degree of accuracy that the errors are negligible in comparison with the errors in other parts of our knowledge of the earth. The probable error of the equatorial radius is less than 1/300000 part, and of the polar semidiameter is about the same.

The three physical constants of the earth, and of its different parts, on which you are now asked to concentrate your attention are the density, the modulus of elasticity, and the strength.

It is important to know as much as possible about the density. The more one knows about the density in all parts of the earth the more surely and safely one may proceed in learning other things about the earth.

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[1] "Preliminary Results of Measurements of the Rigidity of the Earth." *The Astrophysical Journal*, 1914, vol. 39, p. 97.

The modulus of elasticity at each point in the earth controls the behavior of the earth under relatively small applied forces.

The strength of the earth, at each point, as measured by the stress-difference at that point necessary to produce either slow continuous change of shape or rupture, decides the behavior of the earth under the greater forces applied to it.

As to density we know that the earth's surface density is about 2.7, that the density probably increases continuously with increase of depth, that the density at the center is probably about 11, that the mean density is about 5.6, and that within a film at the surface of a thickness of about one fiftieth of the radius of the earth there is isostatic compensation which is nearly complete and perfect as between areas of large extent.

The manner of distribution of the isostatic compensation with respect to depth, and the limiting depth to which it extends are but imperfectly known. Nevertheless it appears that above the depth, 122 kilometers, the compensation is nearly complete even though there may be some compensation extending beyond that depth.

Two general lines of evidence are available in determining the modulus of elasticity of the earth, that from earthquake waves, and that from earth tides.

There are many inherent and extreme difficulties in the way of securing reliable evidence as to the modulus of elasticity from earthquake waves.

To 1913 the accuracy of available observations of tides in the solid earth was insufficient to furnish a basis for reliable conclusions. Nevertheless the estimates of the modulus derived from these early observations were a fair approximation to that given by the very recent and much more accurate observations.

Dr. Michelson and those associated with him in the observation of earth tides at the Yerkes Observatory since 1913 have developed a method of observing which is of a new order of accuracy such that the minute changes of inclination at a given point due to earth tides may be determined with an error of less than 1 per cent.

These observations make the modulus of elasticity of the earth as a whole about like that of solid steel, namely, (8.6) (10^{11} C.G.S.).

It is the modulus of elasticity of the earth as a whole which is measured in this case.

It is eminently desirable to determine if possible whether the modulus of elasticity varies with increase of depth. The Michelson apparatus possibly opens the way to such a determination. Suppose that the apparatus is used on the shore of the Bay of Fundy. Twice a day a large excess load of water is placed in the bay by the tidal oscillation and as frequently the water load is reduced below normal. The stresses produced in the body of the earth by these changes of

load applied over an area only about 30 miles wide are probably confined almost entirely to the first 100 miles of depth. The magnitude of changes of inclination produced at an observing station on the shore by the changing water load would, therefore, be dependent primarily on the modulus of elasticity of the material below and around the bay to a depth of less than 100 miles. The observations might serve, therefore, to determine a modulus of elasticity of the surface portion of the earth rather than of the whole earth.

Turn now to the third of the physical constants, which it was proposed to examine, namely, the strength.

Among the forces which we may consider as furnishing tests of strength are: (1) The forces involved in earthquakes, (2) the weight of continents, and (3) the weight of mountains.

The forces which produce the more intense earthquakes evidently cause stress differences locally, which are beyond the breaking strength of the material. However, from earthquakes we may obtain but little information as to the strength of the earth material, because the intensity of the stress differences can not be reliably determined. We know simply that the intensity exceeds the breaking strength of the material at the points of rupture.

It is uncertain how great are the maximum stress differences produced by the weight of continents. One great difficulty in computing these stress differences arises from the fact that the isostatic compensation of continents, now known to exist, reduces the stress differences much below what they would otherwise be. Love computed the maximum stress differences thus reduced as 0.07 ton per square inch. Darwin computed the greatest stress difference due to the weight of the continents, without isostatic compensation, as 4 tons per square inch. If each of these computations were based upon assumptions, which correspond closely with the facts, one should be warranted in drawing the conclusion that the maximum stress difference caused by the actual continents, supported in part by the actual isostatic compensation, is between 0.07 and 4 tons per square inch, and that it is much nearer to the smaller than to the larger value. But a close examination of either of these computations shows that it is based upon assumptions made to simplify and shorten the computations, which assumptions depart widely from the facts and tend strongly to make the computed stress differences much smaller than the actual. For example, both Darwin and Love used in their computations hypothetical continents, represented by regular mathematical forms, in the place of the actual continents with their many irregularities. The maximum stress difference caused by the actual continents is necessarily much greater than would be produced by the assumed smoothed out, regular, symmetrical continents.

Similarly no adequate computations have been made to determine the maximum stress difference due to the mountains. Darwin computed the maximum stress difference produced by two parallel mountain ranges, of density 2.8, rising 13,000 feet above the intermediate valley bottom, to be 2.6 tons per square inch. Love, for the same mountain ranges, but with isostatic compensation taken into account, computed the maximum stress difference to be 1.6 tons per square inch. In this case the computation indicates that the isostatic compensation reduced the maximum stress difference to but little more than one-half what it would otherwise be. Here, again, both the computed maximum stress differences have been greatly reduced by substituting hypothetical smoothed-out mountains in the place of the actual, irregular, unsymmetrical mountains.

To the person who is trying to get a true picture of the present state of stress in the earth, two very important facts are made evident by a comparison of the Love and the Darwin computations. First, the existence of isostatic computation greatly reduces the stress differences which would otherwise be produced by the weight of the continents and mountains. Second, the depth at which the maximum stress difference tends to occur is evidently very much less with isostatic compensation than without it. These two conclusions, based upon the differences between the two computations, are apparently reasonably safe even in spite of the same wild assumptions on which both the computations were based.

Note that even a little information as to the distribution of densities—a little information about isostatic compensation—profoundly modifies the conclusions as to the state of stress in the earth. It should, therefore, be clear why it was so emphatically stated in an earlier part of this address that information as to the distribution of density in the earth is necessary in order to make safe progress in learning other things about the earth.

Is the earth competent to withstand without slow yielding the stress differences due to the weight of continents and mountains, the isostatic compensations being considered? From the computations by Darwin and Love, considered in the light of the assumptions made by them to simplify the computations, I estimate that it is probable that the actual mountains and continents with all their irregularities of shape and elevation possibly produce stress differences in some few places as great as 4 tons per square inch, and certainly produce stress differences at many places as great as two-tenths of a ton per square inch. The material would certainly yield slowly under such stress differences especially when they persist continuously over long periods of time and throughout large regions. Four tons per inch is the breaking or rupture load for good granite,

one of the strongest materials existing in the earth in large quantities. Two-tenths of a ton per square inch is the safe working load used by engineers for good granite. There is abundant evidence from laboratory tests that the so-called yield point on which the engineer bases his estimate of safe working load for a given material is a function of the length of time the load is applied and the delicacy of the test. The longer the time of application and the more refined the test to determine the permanent yield the lower the observed yield point. In the case of the test in progress in the earth the time of application is indefinitely long and the test is extremely refined inasmuch as the minimum rate of yielding which may be detected is exceedingly small.

If an engineer wishes to know whether a bridge, or foundation, or building, or railroad rail is yielding under stress differences which have been brought to bear upon it he looks for evidence of distress, for rivet heads popped off, scaling from the surface, settling, cracks, or even changes in microscopic structure. The geologists have made very extensive corresponding examinations of the earth. Everywhere they find evidence that the earth has yielded. On the one-fourth of the earth's surface exposed to examination, the land, there is no part for which the evidence does not indicate past uplift, or subsidence, or horizontal thrust, or cracking under tension, or cracking produced by shear, or microscopic yielding in detail such as produces schistosity, for example, or some other form of past yielding to stress differences. The physicist studying the earth must take this overwhelming mass of evidence into account and must conclude that the earth habitually yields slowly to the stress differences brought to bear upon it. Please note that I do not assert that the stress differences are all due to gravity.

I propose now to state what are in my opinion probably the lines of least resistance to future progress in studying the earth from the physical standpoint. I propose to outline what I believe to be the most effective methods of attack, and to indicate some of the conclusions which will probably be reached. I am led to this procedure by two considerations. First, I find it possible to state certain of my opinions as to the net outcome of past investigations most clearly in that form—and time presses. Second, I indulge the hope that such an outline which is frankly an expression of judgment based on evidence much too weak and conflicting to be proof, may possibly kindle the imagination of some man or men, and so lead to vigorous attacks upon the problem and to future progress.

In attacking the problems of the earth one should assume at the outset that the phenomena exhibited are very complicated, that they are probably due to various simultaneous actions, and that the various actions are probably closely interlocked, modifying each other,

though some are probably primary in importance and others secondary. Hence the most effective method of attack is probably one which includes a general correlation of apparently widely separated ideas and facts gathered from physicists, engineers, geologists, chemists, etc., and at the same time includes intensive attacks in detail on one after the other of single features of the problems which arise and an intensive working out of the possible consequences of said features.

It should be recognized at the outset that no observed behavior of the earth clearly warrants the assumption that the material of which it is composed differs radically in any way from that accessible at the surface. It should be assumed, therefore, that throughout the earth the materials are a mixture differing from the mixture found at the surface only as the extreme pressure and temperature conditions at great depths directly and indirectly produce differences.

It should be kept clearly in mind that the geodetic evidence from observations of the direction and intensity of gravity indicates simply the present location of attracting masses, the present distridution of density. It furnishes no direct evidence whatever as to past distributions of density or as to changes in density now in progress. But an understanding of the present distribution of density within the earth, especially near the surface, is so necessary to a true understanding of the present state of stress and of viscous flow in the earth that an understanding of the geodetic evidence is fundamental to progress.

Computations should be made in extension of those which have been made by Darwin and Love. The new computations should, however, deal with the actual irregular continents and mountains, not with regular substitutes. The computations should also take into account the bulk modulus of the materials composing the earth; that is, these materials should be assumed to be compressible. Such computations will no doubt be both difficult and long. I believe that even a moderately vigorous attack along this line will show conclusively that the earth does not behave as an elastic body under the large loads superimposed upon it by the continents and mountains. I believe that the computed stress differences will be found to be so large that the computation will be essentially a proof of viscous yielding.

Next make the contrasting assumption that the material composing the earth is competent to withstand but little shearing stress, and that the pressure at any point is that due to gravitation acting on the mass in the column extending from the point vertically to the surface. Let it be assumed that isostatic compensation exists, is uniformly distributed with respect to depth, and is complete at depth 122 kilometers. Consider the actual topography and form a mental

picture as accurately as possible of the viscous flows which would take place on the assumption that at each level the material would flow horizontally from regions of greater pressure to regions of less pressure along lines of maximum rate of change of pressure, and that the time rate of such viscous flows would tend to be proportional to the space rate of change of pressure. The flows would all be found to be away from beneath high regions toward low regions, from continents toward oceans, from mountains toward valleys.

After such a picture has been clearly formed assume that the isostatic condition is disturbed by long-continued erosion and deposition, producing changes in the surface elevations and surface loads. On the same assumptions as to the nature of the viscous flows as before, form a new picture of the viscous flows which would now be in progress. It will be found that under the new conditions the viscous flows near the surface would still be away from high areas and toward low areas, but in general they would be slower than before. At greater depths, however, it will be found that the viscous flows would be undertows from regions of recent deposition toward regions of recent erosion. These undertow flows would in general tend to be in the direction opposite to recent surface transportation of material. This picture would serve as a first approximation to an understanding of the mechanism of isostatic readjustment. The undertows would be found on these assumptions to extend to a considerable depth, certainly more than 122 kilometers.

Next one should picture the changes in density which would be produced by the viscous flows. The density should be pictured as decreasing in regions from which material is being carried away by the flow and increasing in regions to which the material is being carried. It will be noticed as soon as such a picture is formed that every undertow flow at any level tends to equalize pressures at lower levels. This will have a strong tendency to make the prevailing undertows occur at much higher levels than they otherwise would.

Let it be assumed that the viscous material offers some small resistance to shear and still have elastic properties to a slight degree. The condition assumed originally that the pressure at a point depends simply upon the weight of the material above that point will be disturbed thereby. Form as clear a conception as possible of these disturbances and the modifications of the flows produced by them. I believe the modifications will be found to be important and that they will be found to be such as tend to confine the effects of surface changes of load to a depth which is a small fraction of the radius.

So much for the direct effects of gravity which it seems important to picture clearly. Next study other effects, some of which are indirectly produced by gravity.

First study the modifying effects of changes of temperature. Wherever viscous flow takes place in the quasisolid portions of the earth there heat is necessarily developed in amount equivalent to the mechanical energy expended in overcoming the resistance to flow. This will tend to increase the volume of the material, to increase the pressure, and to raise the surface above the region of viscous flow. It is probable also that the increase of temperature will tend to weaken the material, thus emphasizing the weakening produced by the damaging mechanical effects of the flow.

This temperature effect is probably locally important.

Beneath areas of recent deposition the temperature of a given part of the buried material will slowly increase for long periods of time, on account of heat conducted up from below and prevented by the new blanket of deposited material from rising to the surface so freely as before. Conversely, beneath the areas of recent erosion the temperature of a given portion of material will decrease. The ultimate limit of change will tend to be in each case not greater that about 1° C. for each 32 meters of depth of erosion or deposition. These temperature changes tend ultimately to lower areas of recent erosion and to raise areas of recent deposition, possibly as much as one-thirtieth of the thickness of the erosion or deposition, the temperature effect taking place much later than the erosion or deposition which initiated it.

Study next the effects which may be computed from the bulk modulus of elasticity. Beneath areas of erosion a given particle of matter tends to rise by an amount which may be computed from the bulk modulus of material, and similarly a particle tends to fall beneath an area of deposition. If the depth to which the elastic phenomena extend is as great as 122 kilometers and the bulk modulus is 500,000 kilograms per square centimeter (corresponding to granite) the rise or fall of a particle near the surface will tend to be at least one-fiftieth part as great as the thickness of the material eroded or deposited. This is a change so large as to have considerable effects in modifying or magnifying the actions which would otherwise occur. Possibly this elastic change is much larger than the estimate here given. Of course if the erosion or deposition takes place in a small area only, such elastic response will be largely inhibited by surrounding material on which the load has not been directly changed. But under large areas of erosion or deposition such action must take place and extend to depths possibly as great as 122 kilometers.

Study next the modifying effects, on the phenomena already pictured, of chemical changes which are probably produced in the earth by changes of pressure. The expression "chemical changes" is here used in the broadest possible sense. A relief of pressure at

any given point in the earth necessarily favors such chemical changes as are accompanied by increase in volume and reduction of density. Increase of pressure tends to have the reverse effect. Such changes tend to reenforce and extend in time the effects just referred to which may be computed from the bulk modulus of elasticity. It is important to estimate such changes as well as possible from all available evidence, such for example as that furnished by chemists, by geologists, and by such investigations of rock formation as have been conducted at the geophysical laboratory in Washington. I believe the possible effects of this kind will be found to be so large as to be of primary importance.

Evidence has accumulated during the past few years which makes it reasonably certain that with increased pressure, as at the great depths in the earth, the rigidity and the viscosity of the material also necessarily increases. This tends to cause the viscous flows to take place at higher levels than they otherwise would. This should be taken into account.

Next a reexamination of the conceptions so far formed should be made to ascertain to what extent and how they would be modified if one started with some other reasonable assumption as to the limiting depth of present isostatic compensation or some other reasonable assumption as to the law of distribution of the compensation with regard to depth.

Next full and extensive comparisons should be made between the hypothetical phenomena on the one hand pictured as made up primarily of viscous flows, modified by some elastic effects, initiated in part by surface transfers of load, modified by changes of temperature, modified by chemical changes and in the other ways, and on the other hand the facts of the past as to the behavior of the earth recorded in the rocks and read by geologists and others. This comparison should be used to the fullest possible extent to evaluate the relative importance of the various elements in the actions.

In making this comparison of various hypothetical phenomena with the great accumulated mass of geological facts it should be recognized at once that it is false logic to reason that if a given hypothesis does not account for all the observed facts the hypothesis is necessarily erroneous. On the contrary it is true logic in dealing with such a problem as the earth seen from a physical standpoint to reason that the more facts are accounted for by a given hypothesis the more certain it is that said hypothesis is a statement of a controlling element in the complex phenomena and then to study the facts which appear neutral, or conflicting, with reference to the hypothesis, considering them as indicators of other elements of the

phenomena which one should attempt to embody in other supplementary hypotheses.

I submit that in studying the earth it is a mistake to think that there is any necessary conflict between the idea that the earth behaves as an elastic body and the idea that it is yieldiing in a viscous manner. A body may behave in both ways at once. The earth is probably acting largely as an elastic body under small forces which change rapidly and at the same time is yielding in a viscous manner to forces of larger intensity which are applied in one sense continuously for long periods.

The object of this address will have been accomplished if it serves in time to arouse the imagination and interest of some one and to guide him to greater effectiveness in attacking the problems presented by the earth as seen from the geophysical standpoint.

IV.

VARIATIONS OF LATITUDE: THEIR BEARING UPON OUR KNOWLEDGE OF THE INTERIOR OF THE EARTH.

By Frank Schlesinger.

To review even hastily the contributions that astronomy has made to our knowledge of the figure and dimensions of the earth and the constitution of its interior would consume more time than I can fairly claim as my share. Let me therefore pass over those points that are on accepted ground and are matters of general agreement from the different points of view represented in this symposium; and let me dwell instead upon certain recent developments especially in need of consideration, concerning which the astronomer desires the criticism and help of the geologist, the seismologist, the physicist, and the meteorologist. These developments have come to us directly or indirectly through a study of latitude variations, so that most of what I shall have to say will deal with this subject.

Although variations of latitude are in a sense a very recent addition to our knowledge, yet, on the theoretical side, at least, we find the beginning more than a century and a half ago. In 1755 Euler considered "the rotation of solid and rigid bodies" in a memoir that is now recognized as the foundation stone for our edifice. He showed that if such a body is projected into space it will exhibit two kinds of rotation; the first of these is the familiar one that corresponds to the day in the case of the earth; the other is more subtle and corresponds to the variation of latitude. By reason of this the axis of the diurnal rotation is continually changing within the body, progressing in a regular way, and coming back after a time to its earlier positions. An ordinary top gives us a simple example of this

kind of rotation. The spinner imparts to the top a motion of translation as well as a rotation, and if we wish to study the rotation we must arrest the translation in some way. This we can do by letting the top fall upon a hard surface, in which the iron peg soon wears a minute hole for itself, and the effect is to stop the translation of the top without modifying seriously the rotation. Then we can see that, while the top is turning very rapidly around an axis, this axis is itself rotating in a comparatively leisurely way. Just the same thing is occurring with the earth—the point (or pole) at which the axis of the daily rotation pierces the surface of the earth is continually in motion. If we could take to the neighborhood of the pole a modern instrument and if we could observe there at leisure and in comfort, we should have no particular difficulty in finding the position of the pole within a meter. But if we should repeat these observations a few months later, we should find that the pole had wandered away to some distance. To be sure, this distance would not be great, and all the wanderings of the pole that have thus far been observed could be plotted to true scale on the floor of a room not much larger than the one we are in. Of course, if the pole is moving, so, too, is the earth's Equator; and thus the latitudes of all points on the earth are varying. Such wanderings as these need not disturb the peace of mind of those gentlemen who like to discover the Arctic or the Antarctic Pole. Under the circumstances that the polar explorer must work and with the meager instruments he can transport, he is glad to determine his latitude within half a mile of the truth.

We must understand that it is only in our time, and only after the lapse of many years since Euler published his memoir, that latitude variations have actually been observed. There was nothing in Euler's theory to indicate how large a variation to look for, since this is a matter that depends upon the whole complex of "initial conditions," of which our knowledge is the very vaguest. But this theory does tell us what the period of variation should be, since this depends upon the shape of the earth and the distribution of the material within it, and precisely the information that is here needed is afforded by a study of precession. Applying this information, Euler was able to say that the period of the latitude variation should be 10 months. Bessel at Konigsberg, in 1842, later Peters at Pulkova, Nyren also at Pulkova, Downing at Greenwich, and Newcomb at Washington, all searched their observations for evidence of a latitude variation having a period of 10 months, but all in vain. Astronomers concluded that if latitude variations existed at all, their extent was too small to be detected by instruments of the precision that had then been attained.

Toward the end of the nineteenth century vague whisperings that this conclusion might be incorrect seem to have been in the air.

But the first clear word to this effect came in 1888 from the lips of Küstner, at Berlin. He had invented and applied a method for determining the amount of the aberration of light; but he found that his observations gave well nigh impossible results, agreeing neither among themselves nor with earlier reliable observations. By a nice chain of logic he was able to exclude one possible explanation after another until there was left only the supposition that the latitude of his station had changed while his observations were in progress. Next he examined nearly contemporaneous observations made at other places, and when he found that he could account for certain puzzling discrepancies he no longer hesitated to announce that latitudes were variable after all.

This announcement awoke the liveliest interest and encountered no little skepticism. Special observations were at once set on foot at various observatories in Europe and America, as well as at a station near Honolulu in the Sandwich Islands. These islands are about opposite in longitude to the European stations, and this was the reason for establishing a station there. For obviously if the pole is really changing its place, then the changes in latitude for two opposite stations will be the reverse of each other. When in 1893 this was found actually to be the case, other possible explanations for the observed phenomena at once fell down, and latitude variations became for the first time a universally accepted fact.

Much time and effort have since been expended in attempting to formulate the "laws" of latitude variations and to give them a mechanical interpretation. But observation has shown that the variations are of unexpected complicity, and as a consequence we are still very far from having satisfactory knowledge of this subject. By the same token it is probable that an intensive study of these variations, particularly from points of view other than the astronomical, will teach us much concerning the interior of the earth as well as some of its surface phenomena.

It was the late Dr. Chandler, of Cambridge, Mass., who took the lead in investigating the nature of latitude variations. By overhauling ancient observations (made of course without any reference to the present subject) he was able to trace the presence of the variations back to the time of Bradley in the middle of the eighteenth century. Thus it happens that at the very time that Euler was writing the first theoretical paper on the subject, Bradley had already begun making the observations from which the actual existence of latitude variations might have been proven at once. Chandler was able to gather similar evidence from other miscellaneous series of observations and thus to set down a tolerably continuous record of the variations during a century and a half. However interesting a fact this may be from an historical point of view, it does not help

very much in a practical study of the subject. There are two reasons for this: first, it is only for European stations (and for the most part only for Greenwich) that we have any knowledge of these earlier variations; the other component of the wanderings of the pole, namely that in the meridian at right angles to the meridian of Greenwich, did not begin to be known until very recently. Again, these ancient observations were undertaken for certain definite purposes that they served as well as could be expected for their time; but they were not intended and are not well suited for precise determinations of the latitude. Close acquaintance with the subject has taught us that exceedingly delicate observations are necessary to define the variations with adequate accuracy. If I held in my hands two plumb lines half a meter apart, they would not be quite parallel to each other, though both are exactly vertical; if they were prolonged they would meet somewhere near the center of the earth, 4,000 miles below. The angle between them is a little less than $0''.02$ and represents approximately the accuracy that is demanded and that has recently been attained in latitude observations. This success is due chiefly to the International Geodetic Association which has organized an "international latitude service" of high efficiency, and to whose efforts and experience are due the improvements in instruments and methods that have made possible this extraordinary degree of precision. Since 1899, the association has maintained six observing stations for this sole purpose, two of these being in our own country. One of the minor effects of the war that is now raging in Europe will be the discontinuance of some of these stations. One of the American stations has already been abandoned, and the same fate will overtake the other in June, 1916, unless some independent means of maintaining it, at least temporarily, presents itself soon.[1] An interruption of these observations would be a great pity, for this is one of the cases where a continuous record is highly desirable.

To return to Chandler and his work on these variations, perhaps, the most important of his achievements was to show that the principal term in the variations, instead of having a period of 10 months in accordance with Euler's theory, has in reality a period of 14 months. This difference explains the failure of Bessel and all the others, who preceded Küstner, to find a latitude variation in their observations, for, relying upon Euler's results, they had all tested their observations for the 10-month variation and had sought for no other variation. For the same reason, Chandler's announcement of the longer period was received with incredulity in some quarters,

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[1] Since this sentence was spoken the United States Coast and Geodetic Survey has secured legislation that guarantees the continuation of this station.

and this feeling did not vanish until Newcomb pointed out that Euler had made a certain assumption regarding the interior of the earth that had in the meantime been universally discarded. His period of 10 months applies in fact only to a perfectly rigid and unyielding earth. Newcomb showed that if the earth yields to deformation to the same extent as though it were composed throughout of steel, then Euler's period would be lengthened to about 14 months. Here we have the first dependable determination of the rigidity of the earth, a result that has since been confirmed in several ways, particularly by a measurement of "bodily tides" in the earth.

The 14-month term (or the modified Eulerian term as it is now called) has been under accurate observation for a quarter of a century. The period can probably (though not certainly) be regarded as constant. This is what we should expect, for a change in this period would call for a sensible alteration in the distribution of the material within the earth, or a change in the rigidity of the earth. The amplitude of this term presents a very puzzling problem. Its usual value is about 0″.27, but twice in recent years it has jumped to about 0″.40. Such a change could be accounted for by supposing that the earth had received a severe blow or a succession of milder blows tending in the same direction. We are reminded that both Milne and Helmert have suggested that there might be a direct connection between latitude variations and earthquakes. This suggestion was originally made by Milne very early in this century when the astronomical data necessary to test it were still very meager. It is to be hoped that the question will be taken up again in the light of the information that has been added during the past 10 or 12 years.

Though the Eulerian term is the largest part of the latitude variation, it is by no means the only important one. We have next an annual term with a maximum amplitude of about 0″.20. We may say with some confidence that this term is seasonal and meteorological in its origin, but at present no more definite statement would be warranted. It was early suggested that ocean currents might cause this variation. These currents would have to vary greatly with the season, either in the volume or the speed of the flow, or in its direction; for an unvarying current would merely modify the Eulerian term once for all and would leave the latitude variations otherwise unchanged. A similar suggestion has been made with regard to air currents, and appeal has also been made to unequal deposits of snow and ice on two opposite hemispheres of the earth to account for the annual term. It seems to me that these explanations have not been subjected to the critical numerical tests that are possible and desirable. The meteorological data are doubtless competent to enable us

to compute at least the order of the effects in the latitude variations that we should expect from these various causes. Furthermore, the annual term is probably variable in its amplitude, and it is important to ascertain how (if at all) these changes are related to the corresponding meteorological observations.

One other term must be mentioned in this brief summary. A few years ago Kimura of Japan made the important discovery (the most striking contribution to astronomy that has ever come out of Asia) that the latitudes of all stations are affected by a variation that does not depend upon the longitude but which is the same for all points in the same latitude. In other words, there is present a variation that is not due to the wanderings of the pole. To ascertain more closely the nature of this term, the International Geodetic Association extended its latitude service temporarily to the Southern Hemisphere, with the result that the term was found to be of precisely the kind that would be caused by an annual wandering of the center of gravity of the earth to and fro along the axis of rotation. This must be regarded merely as an illustration and not as an explanation, for so great a change (about 3 meters) in the position of the center of gravity is excluded on other and very conclusive grounds. No plausible explanation for the Kimura term has as yet made its appearance, and as a consequence the reality of the term has been questioned from every possible point of view. Many explanations have been advanced, each of which sought to account for the term as merely an instrumental effect or the like, just as was the case 20 years earlier with the whole of the latitude variation itself. Against such attempts the Kimura term has held up very well. It is not too much to say that at the present time all but one of the numerous explanations of this class have been disposed of; this exception deserves a brief mention, particularly as it calls loudly for the attention of the meteorologist. Let us suppose that the layers of equal density in the atmosphere above a station are not horizontal, but that they are sensibly inclined. If this occurs without our knowledge, as it would under ordinary circumstances, then we should apply refraction to our observations in a slightly erroneous way and we should derive a value for the latitude that is not quite correct. Let us suppose further that this effect were a world-wide one and that in any given month there would be a pronounced tendency for the inclination to be in the same sense in all latitudes, north and south, as well as in all longitudes. Then we should have a set of circumstances that would account for the Kimura term as an atmospheric effect, and therefore it would be excluded as a real variation of latitude. So far as the astronomer is able to testify, the evidence is against the occurrence of such tilts in the atmosphere. The

inclination required to account quantitatively for the amplitude of the Kimura term is over 2 minutes of arc, or a slope of about one part in fifteen hundred. Presumably, in a few years we shall be able to say something more definite as to the possibility of the existence of such conditions. My own opinion is that this explanation, like so many others of similar character that have been suggested for the Kimura term, will be found untenable. Further, I venture to think that latitude variations as a whole will find their explanations less on the surface of the earth and more in its interior than seems now to be the generally accepted opinion.

DRY LAND IN GEOLOGY.[1]

By Arthur P. Coleman.

INTRODUCTION.

After visits to South Africa, Australia, and India to study dry-land deposits it has become very evident to the writer that most of the earth is covered with water, and also that a ship is the most tantalizing of all modes of travel for a geologist, since captains have a prejudice against anything of geological interest, such as rocks or reefs or shoals. After 1,200 miles of sheltered voyaging behind the great Australian barrier one may reach Java without ever seeing a coral reef at close quarters. Except the oozes dredged from the deep sea and the contours of its bottom revealed by soundings, the three-quarters of the globe beneath the ocean have scarcely any message for the geologist. That the waves and the tides do important geological work is true, but to hear the growl of the breakers and to see them pounce on their prey, one must travel in a small boat close to shore and not in an ocean liner. Even to study the action of the sea on the shore it is better to be on land. The dry shores of Lake Bonneville, as read by a Gilbert, give more instruction in regard to wave work than all the foam and tumult of the surf on the strand.

The geologist is essentially a land animal, and yet until recently most books on geology, especially textbooks, have had surprisingly little to say of the land and its conditions. The writers seemed all to belong to the blue-water school, so much of their space has been given to the sea and its inhabitants. It is true that continents were mentioned, almost apologetically, when one came to the Cenozoic mammals, but even the Glacial period did not lift geology above the sea for some of the older writers, who preferred icebergs to glaciers for the manufacture of bowlder clay.

[1] Presidential address read before the society Dec. 29, 1915. Reprinted, by permission, from Bulletin of the Geological Society of America, vol. 27, pp. 175–192, Mar. 31, 1916.

This concentration on the sea and its life went to astonishing lengths in the more ancient parts of geological history. Like most of our older geologists, my first nourishment in the science was drawn from Dana's "Manual." Unfortunately that earliest of textbooks has been lost, but curiosity led me to glance over his fourth edition (1895) to see how the dry land fares in its pages.

There is the usual fiery introduction to historical geology, dividing Archean times alliteratively into Astral, Azoic, and Archeozoic eons, with a lithic era beginning at 2,500° F. and an oceanic era commencing when the earth had cooled to 500°, followed by eras of the earliest plants and the earliest animals as the boiling ocean cooled to endurable temperatures. When the streaming waters had permanently condensed in the hollows of the original crust there was left a V-shaped nucleus of dry land about which the continent of North America was to be built up. After this encouraging start with a quite respectable dry-land area as a foundation, historical geology becomes submerged in seas, mostly shallow, until the end of the Silurian. Out of 114 pages devoted to this part of the world's history the total number of lines referring to the land and its inhabitants amount to only one page, while the Devonian land plants and animals are given only 4 pages out of 46. It is true that most of the Carboniferous chapter is devoted to the rank growths of the coal swamps, but these amphibious plants have little to do with actual dry land. They never rise far above sea level and are frequently lowered beneath it to get a fresh covering of mud or sand. The araucarias of the hills inland are barely mentioned, and it is not till one gets well on into the Mesozoic that the dinosaurs compel the student to depart a little from the seashore. Even then there is a suggestion that at least some of the clumsy beasts preferred splashing along the mud flats or paddling in the lagoons. There is no hint of lean creatures hastening with long strides to the shrinking water holes of a semiarid region.

Another stand-by of student days, this time in Germany, was Credner's "Geologie," which up to the end of the Devonian gives 2 pages out of 58 to the land and its dwellers. Only 32½ pages out of 300, up to the beginning of the Quaternary, have to do with terrestrial things, even the dinosaurs almost escaping notice. The dry land was evidently of small importance.

It is not unnatural that in the beginning geology should devote itself mainly to things marine, for the favored haunts of men are almost all founded on stratified rocks. Werner's idea of a world deposited layer by layer from a primeval sea seemed reasonable when he lectured in Freiberg, though the Bergakademie stands on eruptive gneiss; and when William Smith began stratigraphic geology, on an island where one can never get many miles from the

sound of the surf, he had to collect sea shells from the rocks as coins with which to date the formations.

The regular succession of marine faunas in the stratified rocks laid the foundation for our chronology, showed the orderly development of living beings, and made possible the correlation of the rocks of different countries. The study of marine fossils was necessary to the building up of historical geology on a sound basis, therefore, so that the almost exclusive attention given to the seas and their life was not unjustified. In those earlier days continents had a place in geology mainly as limiting the migrations of marine faunas or as providing sediments for the shallow seas. In other respects they were largely negative things, vacuums where nothing took place, since they provided no fossil-bearing beds, while the waters around them were swarming with life and activity.

It seemed quite the correct thing 35 years ago, when the older men among us were students, to spend most of our time bending over rows of brachiopods in museum cases and memorizing lists of type fossils, so as to fix the age of rocks we might encounter in our field work. In those days the wash of the waves and the smell of the seashore seemed to permeate geology, and dry land was seldom mentioned or thought of by professors or students. Most of geology consisted of stratigraphy and invertebrate paleontology. Bluff old Credner has some justification for devoting nine-tenths of his historical geology to a consideration of the doings of the sea and its inhabitants. The land had scarcely been discovered. Even the "Age of Mammals" was named and subdivided in accordance with the proportions of extinct to living shellfish and not from the rapid evolution of the mammals and their differentiation into the highest forms of animals the world has known.

DISCOVERY OF THE LAND.

It can not be said that the early geologists entirely ignored the land. An unmistakable land surface, like the "dirt bed" of the English Purbeck, with its araucarian stumps still rooted in the soil, was occasionally recognized, though such occurrences are almost unknown in formations older than the Carboniferous. It was recognized, also, that heat and drought best accounted for the beds of gypsum and rock salt found in several of the more ancient formations, though the materials might have come from the evaporation of inclosed arms of the sea, and so might not be really continental deposits.

The most typical land deposits, those of arid and of glacial climates, were seldom recognized as such and were generally included among the marine stratified rocks, though the absence of fossils was

disquieting. Even the red sandstones, with their hot, desert colors, were often looked on as marine, or else possibly as formed in great lakes, because they contained no marine fossils. The ancient bowlder clays were merely coarse, water-formed deposits of some peculiar kind.

In most cases, however, dry-land periods are not represented by deposits of any sort, but by the gaps in the sequence of formations, for normal land conditions mean erosion and denudation. Their only record is usually a discordance, and a dry-land interval shown only by an unconformity naturally passed almost unnoticed. Most of the chapters of the world's history are written under water and show a strong bias toward the side of the water animals.

The only continental deposits beside those of arid and glacial conditions which have a good chance of being preserved and recognized are those of the coal swamps, and they persist mainly because they are on debatable ground often invaded by the sea. During much the greater part of the world's history happenings on the land are recorded only in the most accidental way, as by some stray leaf or tree trunk or carcass drifting down a river to be buried in the mud at its mouth. It is seldom that land formations can be found on a broad enough scale to reconstruct continental surfaces and conditions.

Though it is certain that lands and their inhabitants have existed in unbroken succession from early times, the lands themselves are in geology mostly shadowy things. Whether they were mountainous or flat we can only infer from the kind of sediments they sent down to the sea.

During most of the world's history the climate seems to have been mild and moist, even to the poles, and deserts and ice sheets were apparently absent. We are living in an exceptional time characterized by extremes of climate and are apt to think of such extremes as normal. When Miocene plane trees grew luxuriantly on Spitzbergen, in latitude 78°, the whole circulatory system of air and water must have been different from the one we are accustomed to. Extremes of cold and perhaps also of dryness must have been largely absent. There could have been no cold ocean currents flowing beside warm lands to desiccate the winds blowing over them, as in southern California and northern Chile, at the present time. The most characteristic land deposits, those of deserts and ice sheets, belong especially to the short periods of stress and trouble separating the long, genial, but unenterprising, geological ages, and hence must be relatively rare in the column of formations.

These comparatively unusual types of deposits began to attract attention about 60 years ago in Europe, and geologists of the Indian survey correctly interpreted the ancient Talchir bowlder-clays in 1859.

With deserts before their eyes for comparison, they recognized also ancient arid deposits. In America not much attention was given to continental formations till Davis and his brilliant physiographic school, 25 years ago, began to explain the Cenozoic beds of the west as dry-land deposits. At about the same time Walther and other Germans took up the careful study of desert processes, giving the clue to the origin of ancient red sandstones and their accompaniments. Of late years most of us have paid at least brief visits to deserts and have felt the charm of their bareness, their loneliness, their clear, cool, night skies and hot orange haze at noon, and have watched the dusty pillars of the "go-devils" transport a train-load of dust across the Kalihari, or have seen the low dance of the yellow sand grains as a hot wind builds up a barchan in Nubia. We have seen the selective carving of the desert sand-blast on rocks of unequal hardness, have wondered at the brown desert varnish on exposed rock surfaces, and have speculated as to the origin of "calcrete" or "kankar."

Geologists are now on the alert for continental, and especially desert, formations, and there are few red sandstones which have not been picked out of the marine ragbag and set aside as belonging to the land. It is even possible that the pendulum has in some cases swung too far and will have to swing back again. Some of the red sandstones or shales handed over to the desert may yet disclose marine fossils and have to return to the seashore.

A glance through recent textbooks of geology in English, French, and German shows how widely attention has been given of late years to continental, and especially desert, formations. Arid conditions have been recognized, or at least suspected, in nearly all the main subdivisions of historical geology. They have been mentioned by one author or another in the Pleistocene, the Pliocene, the Miocene, the Eocene; the Cretaceous, and the Triassic; the Permian, the Carboniferous, the Devonian, the Silurian, and the Cambrian; the Keweenawan, and possibly one or two earlier of the pre-Cambrian series. In fact, only the Jurassic and the Ordovician seem to have escaped the drought, and it may be that a more careful search through the literature would disclose deserts there also.

A number of the suggestions noted are only tentative, however, and wide-spread and unmistakable desert formations seem confined to the Pleistocene, Triassic, Permian, Devonian, and late pre-Cambrian. Of these the Pleistocene deserts may be looked on as continuing to the present, the Triassic deserts form an aftermath of the arid conditions of the Permian, and the Devonian deserts seem less extensive than the others. The three times of greatest aridity appear to be: (1) The Pleistocene continuing to the present; (2) the Permian-Triassic; (3) the late pre-Cambrian.

Though well known, it may not be amiss to recall some features of these three periods of widely extended desert conditions.

ARID ZONES OF THE PLEISTOCENE AND PRESENT.

The map of the world shows two zones which are largely desert, one in each hemisphere, with a broad zone of heavy equatorial rainfall between. To the north of the northern desert belt there are moister conditions, and the same is true to the south of the southern one. There is reason to believe that Antarctica is arid, evaporation exceeding precipitation, and the same may be true of some Arctic lands. The precipitation on Spitzbergen is stated to be only 6 inches per annum.

The two belts of deserts do not run quite parallel to the Equator. The northern one, beginning with the Sahara and Nubian Deserts, in Africa, runs northeastward through the Arabian and Indian Deserts to those of central Asia, where the desert of Gobi reaches nearly 50° of north latitude. In North America desert conditions are less extensive and do not extend beyond latitude 40° or 45°.

In the Southern Hemisphere the bodies of land are much smaller, and the deserts of South Africa, Australia, and South America are correspondingly small as compared with those north of the Equator. Their southern limits are, roughly, 30°, 40°, and 45° south latitude.

Penck has shown, I think satisfactorily, that these desert belts migrate toward the Equator in cold periods, narrowing the zone of tropic rains, and move respectively north and south in warmer periods. In the mildest geological periods it would almost seem as if the equatorial belt of warmth and moisture expanded to cover the whole earth, abolishing both deserts and ice-sheets, and these appear to be the normal conditions when peneplanation has advanced far and shallow seas transgress widely over the continents.[1]

ARID PERIOD OF THE PERMIAN AND TRIASSIC.

Going back to Permian and Triassic times, much of the evidence has been buried or destroyed; yet it is certain that deserts extended widely in many lands. Red sandstones, arkoses, and shales with mud cracks and footprints, beds of salt and gypsum, are reported from England, Germany, Austria, and Russia in regions now well watered. In North America there were the widespread red beds of the Rocky Mountain region and the band of desert sandstones extending from Prince Edward Island southwest to Virginia; so that arid conditions covered far more of Europe and North America than now. In India

[1] Die Formen der Landoberfläche u. Verschiebungen der Klimagürtel, Koenigliche, Preus. Ak., Vol. 4, 1913.

the Gondwana system includes great thicknesses of coarse sandstone with bands of conglomerate, supposed to be of fluviatile origin, terrestrial deposits, but perhaps not of a specially arid kind;[1] but no other references to Asiatic land conditions have been found. I. C. White reports a thick series of massive red and gray sandstones, probably of Triassic age, resting on Glossopteris beds with coal seams in Brazil, but expresses no opinion as to the climate during the deposition of these upper beds. The basal conglomerate under the coal he thinks glacial.[2] Red beds of sandstone and conglomerate to the thickness of 1,600 feet occur, according to Rogers, in the Karroo system of South Africa, but he puts them probably above the Triassic.[3] Whether the 1,100 feet of Hawkesbury sandstones of the Triassic in New South Wales, with their steep cross-bedding, bands of conglomerates, worm tracks and sun cracks, imply an arid period in Australia is perhaps uncertain, though they are undoubtedly continental deposits.[4]

It will be seen that land formations, often of a very arid kind, are found in most of the continents in Permian or Triassic times. They seem to occur rather later in the regions which endure the cold of the Permocarboniferous glaciation than in Europe and in our Western States, but the correlation is not very certain. These "New Red" deserts following on the heels of the severest ice age on record close the Paleozoic calamitously. It is not surprising that such extreme climatic changes put an end to the lush growths of the coal swamps, so that only hardy plants survived, and hastened the departure of the semiaquatic amphibia, while giving an impetus to the development of the reptiles as dry-land inhabitants.

There must have been very dry conditions during the Upper Silurian (Salina) of America, as shown by the salt and gypsum beds of New-York, Ohio, Ontario, and Manitoba; and the succeeding Old Red beds of Scotland and other European countries suggest a similar climate, but I have not found evidence of arid conditions on a wide enough scale to make it desirable to discuss them here.

LATE PRE-CAMBRIAN DESERTS.

Desert characters have been ascribed to sandstones, perhaps belonging to the earliest Cambrian, but more probably the uppermost pre-Cambrian, in many parts of the world. They include apparently the Keweenawan and part of the Belt series in America, the Torridonian of Scotland, part of the Gaisa beds of Norway, perhaps also the Sparagmite of Sweden and the Jotnian of Finland. Whether

[1] Oldham: Geology of India, 2d edition, pp. 150–151.

[2] Brazilian coal fields, p. 31.

[3] Geology of Cape Colony, p. 216.

[4] Geology of New South Wales, Suessmilch, pp. 158–160.

the Matsap beds of Cape Colony and some of the Kuddapah sandstones of India, described as shore deposits, or the Vindhian sandstones and conglomerates should be included is uncertain.

If these are all of the same age and have been correctly interpreted as arid deposits, this was the most severe and extensive period of desert conditions known. In many places on the Canadian Shield the coarse red sandstones, usually with some conglomerate at the base, may be seen resting on an Archean surface of granitoid gneiss or Keewatin schist or Animikie slate, the original land surface of gently rounded hills and shallow valleys belonging to an ancient peneplain. In some outcrops the crumbling gneiss beneath, an old regolith, provides most of the materials for the basal conglomerate. This is true at various points on the north shore of Lake Superior and apparently also in Scotland, where the Torridonian rests on the Lewisian. The Lake Superior Keweenawan, though much the best known, is on a small scale as compared with the areas of sandstone of the same age farther north in Canada. The Athabasca sandstones of Tyrrell, those of Great Bear Lake and of central Labrador, not to speak of smaller areas, indicate a very broad surface exposed to arid conditions in North America. These red sandstones still occupy not less than 50,000 square miles, and it is certain that much greater areas of such relatively soft and easily attacked rocks have been destroyed in the long dry-land periods of later times.

It appears that in this desert period the arid districts were mainly in the Northern Hemisphere and to the north of latitude 48°—that is, very much farther north than the belt of deserts of the present Northern Hemisphere. It is unknown, of course, to what extent Keweenawan rocks are buried to the south of Lake Superior or of Scotland. The breadth of the belt as known in North America is at least 20°, since rocks of this age reach nearly to 70° north latitude in the region north of Great Bear Lake. The Gaisa beds on Varanger Fjord, in Norway, reach the same latitude, and the Scotch Torridonian about latitude 58°.

It is hard to imagine red soils, drifting sands, and the hot winds of deserts as existing in regions now tundra-covered and frigid; but this seems to have been true in the more northern areas.

GLACIAL PERIODS.

Thus far arid conditions only have been mentioned, but the best preserved land surfaces of the past are those sealed up unchangeably beneath glacial deposits. It seems absurd to couple together deserts and glaciers, so opposite to one another in every respect; nevertheless in running down the column of historical geology one finds these contradictory phenomena closely linked together. In almost all the

periods where aridity has been proved there have been found also proofs of ice action, the two seemingly hostile conditions occurring either at the same time in different parts of the world or one after the other in the same region. We live in the closing stages of a great Glacial period, extensive ice sheets still surviving in Greenland and the Arctic Islands, as well as in Antarctica, and yet wide deserts are found in all continents save Europe.

More or less certain evidence of ice action has been found in the Pleistocene, the Eocene, the Cretaceous, the Triassic, the Permian, or Permocarboniferous, the Carboniferous, the Devonian, or possibly Upper Silurian, perhaps the Cambrian, certainly the late pre-Cambrian, and the Lower Huronian. The list just given is closely parallel to that given for the arid periods.

Only four of these glacial times are of prime importance—those of the Pleistocene, the Permocarboniferous, the late pre-Cambrian, and the Lower Huronian.

PLEISTOCENE ICE AGE.

The Pleistocene ice age, from which the world is just emerging, unless this happens to be an interglacial period, is so familiar that little need be said of it. Bowlder-clay, moraines, and deposits formed by glacial waters occur over 6,000,000 square miles of the Northern Hemisphere; smaller areas are found in the Southern Hemisphere, and Pleistocene moraines reach thousands of feet below the present glaciers on high mountains all over the world, even under the Equator, showing that the climates of the whole world were affected. Beneath the glacial deposits in many places there are characteristically smoothed and striated rock surfaces, though near the edges of the ancient ice sheets there are thousands of square miles where loose materials were not swept away to bedrock. The central areas were most effectively scoured, and in many places the rocks beneath, owing to unequal hardness, have been shaped into roches moutonnées, forming hills well rounded on the side from which the ice advanced. Bowlder-clay is a highly specialized product of land ice; floating ice, such as floes or bergs, is not known to produce it, the materials dropped through the water when melting being necessarily more or less stratified. The "soled bowlders" or "striated stones" from bowlder-clay have special characters not caused by any other agency, such as mudflows or torrential action. They are manufactured articles, easily recognized by one familiar with glacier work, and not to be confounded with stones scratched or smoothed in other ways. These familiar features are recalled because they serve as criteria for the recognition of the ancient glaciations to be mentioned later.

The hummocky, moutonnées surfaces left by the Pleistocene glaciers on Archean rocks which have disordered structures and vary in durability are very characteristic and were once looked on as the direct handiwork of the ice sheets themselves. The clean and polished surfaces of fresh rock, generally well striated and often deeply scored, are eloquent of the stripping and grinding of the glacier, but the original surface forms have not been greatly changed, as will be shown later.

Most of the great Pleistocene ice sheets gathered on comparatively low ground and reached sealevel, often occupying large areas of shallow sea-bottom as well as the land. Few of them began in mountain regions, and the flow of those on level ground was caused by the slope of the upper surface of the ice mass and not by the inclination of the floor beneath. They could even move uphill for thousands of feet, when the ice sheet was thick enough in the center, and their flow took place outward in all directions.

Doubtless conditions were similar in earlier glaciations, and it is not necessary to assume great mountain ranges to account for them, as some geologists have done.

PERMOCARBONIFEROUS ICE AGE.

The first undoubted proofs of ancient glaciation seem to have been found by the Blandfords in India, and the first memoir of the Indian survey (1859) contains a brief account of the Talchir tillite in central India, illustrated by a rough sketch. Soon after South African and Australian tillites of the same age were described. There was at first a good deal of skepticism expressed by European and American geologists as to the reality of the discoveries. Ramsay's interpretation of certain English bowlder conglomerates as glacial a few years before had been disputed, which cast doubt on the new reports from the far east and south. Was not the Carboniferous a tropical time, even in the Arctic regions? Glaciers and the steamy coal swamps did not mix well together.

Since then, however, many northern geologists, including expert glacialists, have studied these marvelous deposits, and for a number of years no one has doubted their glacial origin, in spite of the fact that most of the localities are in what are now warm, temperate, or even tropical regions. All the evidences for the ice action on a large scale found in our Pleistocene are repeated, with the difference that the Pleistocene till ceases about 38° from the Equator, while the Talchir tillite in India reaches well within the Tropics (18° North) and Permocarboniferous tillite in West Australia touches the Tropics. In South Africa the Dwyka tillite reaches 24° 30′, or even 22°,[1] and

[1] For literature see Glacial periods and their bearing on geological theories, by the writer. Bull. Geol. Soc. Am., vol. 19, pp. 347–366; and Schuchert: Climates of geologic time. Carnegie Inst., Pub. No. 192, pp. 265–298.

I. C. White and Woodworth report similar tillites between 25° and 30° in southern Brazil.[1] New localities have been reported within the last few years in Argentina [2] and the Falkland Islands; [3] but only few and unimportant occurrences are known in the Northern Hemisphere outside of India. They have been reported from Herat in Afghanistan, Armenia, and the Urals; and in western Europe they have been described from central France [4] and the Frankenwald.[5] In North America tillites, probably of the same age, have been found by Sayles near Boston [6] and by Cairnes on the Alaskan boundary.[7]

A year ago, near Penganga River, under the hot sun of India, in latitude 19° or 20°, I walked across fields of ancient till strewn with glaciated stones and bowlders and stood on a well-polished and striated surface of Vindhian limestone, as typical as can be found in Ontario or northern New York. This resurrection of an ice-worked surface of the Paleozoic, in what are now the sweltering Tropics, gives a glacial geologist something to ponder over; and to see the same things in Africa and Australia, only on a much larger scale, as I have had occasion to do within the last few years, raises some of the most thrilling problems in all geology.

Our Pleistocene ice age, with its array of glacial and interglacial beds, was merely an imitation on a much smaller and less impressive scale of the tremendous Paleozoic ice age, which laid down in places 1,000 feet or more of till and included interglacial times long enough to form great coal seams, as in the Greta beds of New South Wales.

These ancient bowlder-clays and moutonnées rock surfaces of the southern continents bring us face to face with the most dramatic moment in geology, when a world, enervated by the moist, hot-house conditions of the earlier Carboniferous, found itself in the grip of the fiercest and longest winter of the ages, followed by the merciless droughts of the Permian and Triassic.

LATE PRE-CAMBRIAN ICE AGE.

Still more ancient tillites have been found in a number of regions, sometimes described as Lower Cambrian; at others as Uppermost pre-Cambrian. In a few cases Cambrian fossils have been collected in beds above the tillite, but, so far as I am aware, never beneath it.

[1] Brazilian coal fields, pp. 11–15; and geological expedition to Brazil and Chile. Bull. Mus. Comp. Zool., Harvard, vol. 56, No. 1.

[2] Keidel: Compte Rendu, Geol. Congress, XII Session, 1914, p. 676.

[3] Halle: Geol. Mag., n. s., Dec. 5, vol. 5, pp. 264–265.

[4] Compte Rendu, 1895, vol. 117, p. 255. Striated stones and angular blocks up to 12 or 15 cubic meters are described.

[5] J. D. G. G., 1893, vol. 45, p. 69. Bowlders occur scattered through unstratified graywacke in the upper Culm.

[6] Sayles and La Forge: Science, n. s., vol. 32, pp. 723–724; also Harvard Bull. Mus. Comp. Zool., vol. 56, No. 2.

[7] G. S. C., Mem. 67, Alaska Boundary Survey, pp. 91–92.

It is possible that there were two early ice ages, with an interval between; but it seems more probable that they are of the same age and all really pre-Cambrian. The Australians believe that their more ancient tillites are Cambrian, however.

Tillites have been suggested at two places in the Keweenawan of America. They occur in the Gaisa beds of Norway, where there is a striated surface beneath; perhaps also in the Torridonian of Scotland. In Australia Howchin describes an area of 460 miles by 250, and they are found also in Tasmania. They are reported from the Nant'ou formation in China; the Griquatown series in Cape Colony, where they have an area of at least 1,000 square miles, and near Simla, in India. The last two mentioned may be older than the Keweenawan. Sir Thomas Holland thinks the Simla tillite may even be as old as the Huronian.

These tillites belong to higher latitudes than those of the Permo-carboniferous, none coming nearer the Equator than 29°; but some of them occupy regions now warm temperate, while the ice sheets of the Pleistocene halted at about 38° in North and South America and 52° in Europe. In so old a period one can hardly expect to find very complete evidence of the area covered by glaciers; but this ice age seems to have been more severe than that of the Pleistocene.

HURONIAN ICE AGE.

Much farther off in the abyss of pre-Cambrian time is the Lower Huronian Glacial period, thus far known with certainty only from the Canadian Shield, unless the tillite reported by Hintze from the Wasatch Mountains and that from Simla in India are to be referred to so early an age. A characteristic tillite with well-striated stones has been found in the famous Cobalt region, its hard bowlder-clay cut by the richest veins of native silver in the world. Striated stones have been found also 60 miles to the east, in the Province of Quebec, by members of Morley Wilson's geological survey party,[1] and one from the original Huronian region, 160 miles to the southwest, has been figured by Collins.[2] Areas of similar coarse bowlder conglomerate or tillite, sometimes inclosing blocks tons in weight and miles from their source, have been mapped at various points as far northeast as Chibougamau, 320 miles from Cobalt, and have been found also to the west of Cobalt. They are widely scattered over the Canadian Shield and were once much more extensive, covering, no doubt, many thousands of square miles.

In most cases the tillite rests with gentle dips on the low hills and shallow valleys of a peneplain closely resembling the present Lauren-

[1] G. S. C., Mem. 39, pp. 88-97.

[2] G. S. C., Museum Bull., No. 8, plate 1.

tian peneplain. In some places the tillite passes downward, with no visible break, into an old regolith due to the decay of the Laurentian gneiss or Keewatin greenstone beneath. In others the rock below has been smoothed and polished, though no striæ have yet been found on it.

It is impressive to come on this old land surface half way down in the pre-Cambrian succession, yet as thoroughly baseleveled as the neighboring undulating surface of gneiss and greenstone, from which rain and frost are now stripping the bowlder clay. The continent sealed up beneath the Huronian tillite looks as finished and as ancient as the Laurentian peneplain beneath the bowlder clay of the last ice age. The strenuous history of the world since Huronian days could add nothing appreciable to its hoary antiquity. Great mountain ranges had already been gnawed down to the bare crystalline foundations before the ice of the Huronian covered the surface with bowlder clay, and this all happened long before a trilobite was entombed in the mud of a Cambrian sea.

Though the extent of the Huronian ice sheet is only imperfectly known, it is certain that a plain in all respects like that beneath the tillite stretches 2,000 miles northwestward to the Arctic Ocean and more than 1,000 miles northeastward to the edge of Labrador, for flat-lying areas of Animikie or Keweenawan rocks cover a dozen broad areas of similar peneplain in other parts of the Canadian Shield. The same plain slips gently under Silurian and Devonian sediments in the central depression of Hudson Bay, under Ordovician limestone and Potsdam sandstone in Ontario, and under Silurian, Devonian, and Cretaceous rocks toward the southwest. How far the unchanged pre-Huronian peneplain or its little changed successor extends southwestward beneath the stratified rocks is unknown.

Much of this vast surface has been buried at one time or another and sheltered from erosion by marine sediments, and has since been disinterred scarcely modified, but it is probable that it was never all covered by the sea at once. Portions of it seem to have remained dry land as cities of refuge for the inhabitants in every inundation.

That other continental nuclei have had similar histories may be considered certain. In Scotland and Scandinavia nearly horizontal pre-Cambrian beds, whether of glacial origin or not, cover a peneplain closely like ours, and quartzites and conglomerates called pre-Cambrian may be seen resting with gentle dips on a similarly truncated plain in West Australia. Near Clackline, for instance, Huronian-looking quartzite rests on gneiss penetrated by pegmatite dikes, and at several places in the neighborhood of Kalgourlie and

Koolgardie a somewhat tilted conglomerate, like that of the American Huronian, overlies the steeply dipping gneissoid rocks.

PRE-HURONIAN LAND CONDITIONS.

No unchanged land surface has yet been found below the peneplain just described, but important land areas can be inferred with certainty, though now obliterated by squeezing and folding and the metamorphism due to eruptive granites. The great development of clastic sedimentary rocks included under the names of Seine Series, Sudbury Series, Temiscaming Series, etc., widely distributed over the Canadian Shield, imply broad lands and even mountain ranges far older than those destroyed before the Huronian.

They generally begin with a great basal conglomerate, so coarse and bowldery sometimes as to suggest ice action, but squeezed and rolled out and folded in with other rocks in ways that make the finding of striated stones or a striated surface beneath quite hopeless. It is, however, highly probable that the climate was in general cool and moist, for the rocks are gray and often include arkoses, with little weathered feldspars, though Lawson speaks of the Seine conglomerate in one place as "fanglomerate" of desert formation. The rocks as a whole suggest a continental origin, and their materials must have come from the weathering of land surfaces. Some of the graywackes and slates are very evenly bedded and show regular alterations of coarser and finer materials, caused by varying seasons, either warm and cold or wet and dry. They resemble the stratified silt and clay laid down in glacial lakes at the end of the Pleistocene. Sederholm's Bothnian slates, with seasonal banding, probably of somewhat the same age, show similar conditions in Finland.

Land can be discovered still farther down in the misty depths of time, for the pebbles of the Seine and Doré conglomerates include far older sedimentary rocks derived from the Keewatin or Couchiching or Grenville series, showing vast destruction of land surfaces in pre-Laurentian ages at the very beginning of the geological record.

These glimpses of American land surfaces in a past twice removed from the ancient pre-Huronian continent give one a strange vista into a dim antiquity almost infinitely remote from a dweller in the post-Pleistocene. There is no visible beginning to dry land on the continent of America.

WHY SHOULD THERE BE DRY LAND?

Though it is commonly accepted that there were lands in the earliest known times, there are geologists who hold a theory of the origin of the world which logically excludes the possibility of land showing itself above the sea. The original nebular hypothesis, if

followed without mishap from the stage of a cooling gas to that of a liquid, and then of a solid, would result in a correct spheroid of rotation. The lithosphere thus formed would be covered by an unbroken hydrosphere, followed in its turn by an atmosphere. A good workman would certainly have come close enough to the ideal form of his world to prevent errors amounting to 60,000 feet. A properly manufactured world, following the orthodox nebular process, would be completely covered by an ocean 8,000 or 10,000 feet deep.

This ideal world without a continent or an island would have avoided many difficulties. Land animals, blundering, bloodthirsty, even cannibal in their crude instincts, could never have existed. The ocean itself might never have been inhabited if life originated, as is commonly supposed, under shallow-water conditions. How quiet and peaceable such a world would have been! One almost longs for it under the turmoil of present conditions.

A world without land would have had its disadvantages, however. There could have been no geologists and no geology.

But it is idle to speculate as to the possibilities of a landless world. The blunder was committed and the lithosphere was so far warped out of shape that more than a quarter of it rises above the sea. One might inquire, however, whether the blunder might not have been rectified by providing more water, so as to drown out the objectionable lands. We know that there have been times when much of the present continental area was encroached on by the sea. Was there more water then, or was it merely differently arranged? Large amounts of water are withdrawn from circulation by the hydration of various minerals. Are they balanced by the amounts restored as juvenile waters and the steam from volcanoes, assuming, of course, that volcanoes give off steam and not ammonium chloride? Probably most geologists take it for granted that the amount of water on the globe is nearly constant from age to age.

The existence of dry land at all when there is so much water on the earth is a profound mystery not even plausibly explained by the nebular hypothesis, since it demands an inexcusable irregularity in the working of the nebular machinery.

HAVE OCEANS AND CONTINENTS EVER CHANGED PLACES?

Admitting that in the beginning the lithosphere bulged up in places, so as to form continents, and sagged in other places, so as to form ocean beds, there are interesting problems presented as to the permanence of land and seas. All will admit marginal changes affecting large areas, but these encroachments of the sea on the continents and the later retreats may be of quite a subordinate kind, not implying an interchange of deep sea bottoms and land surfaces. The essential permanence of continents and oceans has been firmly held

by many geologists, notably Dana among the older ones, and seems reasonable; but there are other geologists, especially paleontologists, as well as zoologists and botanists, who display great recklessness in rearranging land and sea. The trend of a mountain range, or the convenience of a running bird, or of a marsupial afraid to wet its feet seems sufficient warrant for hoisting up any sea bottom to connect continent with continent. A Gondwana Land arises in place of an Indian Ocean and sweeps across to South America, so that a spore-bearing plant can follow up an ice age; or an Atlantis ties New England to Old England to help out the migrations of a shallow-water fauna; or a "Lost Land of Agulhas" joins South Africa and India.

It is curious to find these revolutionary suggestions made at a time when geodesists are demonstrating that the earth's crust over large areas, and perhaps everywhere, approaches a state of isostatic equilibrium, and that isostatic compensation is probably complete at a depth of only 76 miles. Hayford's results have been ably supported and applied by my predecessor, Dr. Becker, in his address last year, but some geologists hesitate to accept them. Barrell, after an elaborate discussion of the whole question, thinks the equilibrium much less complete than Hayford's results would suggest, but his arguments do not seem entirely convincing.[1] Great stress is laid on the submarine deltas of the Nile and the Congo as loads which should have depressed the floor on which they were laid down, but have not done so. It should be remembered, however, that we know them only from soundings, and that assumptions regarding them are more or less hypothetical. On the other hand, the delta of the Mississippi seems to conform to the theory of isostasy, and there are numerous examples of depression going hand in hand with the formation of shallow-water deposits quite in accord with the isostatic theory. The 14,000 feet of coal measures at the Joggins are an instance. But more convincing still is Fairchild's demonstration that a wave of elevation followed up the retreat of the ice front during the closing stages of the Glacial period. The thickness of ice near its margin could not have been more than a few thousand feet, perhaps half a mile, which would mean in weight of rock only 750 feet. If the stiff carapace of the earth in the State of New York yielded to so slight a change of load it is hardly credible that 9,900 feet of sediments spread over 75,000 square miles of sea bottom off the coast of Africa could have no effect.

If I understand Barrell's discussion aright, his differences from Hayford's conclusions are rather of degree than of kind. He thinks the earth's crust more rigid and considers adjustments to change of

[1] Articles on the strength of the earth's crust. Jour. Geol., vols. 22 and 23.

load much less complete, and also that they are carried out by slow movements in the "asthenosphere" much below Hayford's level of complete compensation at 76 miles below the surface.

He would probably agree that on the broad scale continents are buoyed up because they are light, and ocean bottoms are depressed because the matter beneath them is heavy. He would admit that to transform great areas of sea bottom into land it would be necessary either to expand the rock beneath by several per cent or to replace heavy rock, such as basalt, by lighter materials, such as granite. There is no obvious way in which the rock beneath a sea bottom can be expanded enough to lift it 20,000 feet, as would be necessary in parts of the Indian Ocean, to form a Gondwana land; so one must assume that light rocks replace heavy ones beneath a million square miles of the ocean floor. Even with unlimited time, it is hard to imagine a mechanism that could do the work, and no convincing geological evidence can be brought forward to show that such a thing ever took place.

Discussing this question not long ago in the Journal of Geology, Prof. Chamberlin showed that the only typical case of deep-sea deposits found on land, the well known one of the Barbadoes, occurs on one of the great hinge lines around which motions of the earth's crust take place and has no real bearing on the change of ocean bottoms of continents.[1] The same may be said of the deep-sea deposits on Timor, in the East Indies, recently described by Molengraaff.[2] In position Timor is almost the counterpart of the Barbados in the West Indies.

The distribution of plants and animals should be arranged for by other means than by the wholesale elevation of ocean beds to make dry-land bridges for them. W. D. Matthew's excellent paper on climate and evolution suggests ways in which this may be done more economically.

The elevation of mountain chains by folding or the overriding of blocks might be expected to make trouble for the isostatic theory; but the two best known examples, the Rockies and the Himalayas, seem to be approximately in isostatic equilibrim. In the case of the Himalayas, the youngest and highest of the great mountain systems, it is staggering to find nummulitic beds 20,000 feet above the sea; but however it was managed, enough light material seems to have been introduced beneath to float the mountains at about the proper height.

We may conclude that, broadly speaking, the dry-land areas have always been where they are now. The adjustments of the boundaries of land and sea have been confined to the margins of the continental masses.

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[1] Jour. Geol., vol. 22, pp. 131, etc.
[2] Koninklijke Akad. v. Wetenschappen, Amsterdam, deel 24, pp 415–430.

TELEOLOGICAL CONSIDERATIONS.

There are certain teleological features of the relations of land and water to which attention may be drawn in closing. Without water, no life such as we know would be possible. On the other hand, uniformly deep water over the whole earth, such as might have been expected in a rigidly mechanical scheme, would probably not have provided the conditions necessary for the development of life. An apparently accidental lack of homogeneity in the earth allows lighter parts to rise above what would otherwise have been a universal sea. The combined efforts of the epigene forces since the earliest known times have been directed toward the destruction of continents and islands and their reduction to shoals completely covered by the sea, but their efforts have always been foiled by movements originating in the earth's interior. No continent seems to have been completely submerged since Triassic times. The life of land plants and animals appears to have been uninterrupted since that time on all the continents.

There has been perpetual oscillation in respect to the area and elevation of land exposed, but on the whole the balance has been carefully maintained. But for the presence of oceans of water, of an abnormal lightness in some parts of the earth's crust, and an unfailing balance for 50,000,000 years between the forces of elevation and of destruction, life such as ours would have been impossible. Can we look on these surprising adjustments as merely accidental?

THE PETROLEUM RESOURCES OF THE UNITED STATES.[1]

By Ralph Arnold.

INTRODUCTION.

In 1908 when the agitation for the conservation of our mineral and other natural resources was at its height, a paper was prepared by Dr. David T. Day on "The Petroleum Resources of the United States."[2] It was the privilege of the writer to contribute some of the data upon which Dr. Day based his conclusions. Since the preparation of that article much development work has been done in this country, new fields have been opened up, and the possibilities of the older fields have been more closely studied. The present paper is intended as a revision of Dr. Day's thesis in view of the latest information pertaining to the subject. The writer wishes to acknowledge his indebtedness to the following, among others, who have contributed data used in the preparation of these estimates: James H. Gardner, M. J. Munn, Prof. L. C. Glenn, Prof. G. D. Harris, and Richard R. Hice.

EXTENT OF THE PETROLEUM FIELDS.

The oil fields of the United States usually are classified as the Appalachian, Lima-Indiana, Illinois, Mid-Continent, Gulf, Rocky Mountain, California, and Alaska.

Appalachian field.—The Appalachian field extends from southwestern New York, through western Pennsylvania, southeastern Ohio, West Virginia, and eastern Kentucky, into northern Tennessee. The formations yielding the oil throughout this field include those of the Devonian and Carboniferous. The oil occurs along the axes and on the flanks of anticlines, parallel in general with the strike of the Appalachian Mountains, and on minor terraces or other structures associated with them. Occasionally it has

[1] Reprinted by permission from Economic Geology, Vol. 10, No. 8, December, 1915.

[2] Bull. U. S. Geol. Survey, No. 394, pp. 30–50, 1909.

been found in waterless synclines. The reservoir rocks are principally sandstones and coarse sediments. The oil from this field is of the best quality in the world, yielding a high percentage of the lighter oils such as gasoline and kerosene, and is utilized entirely for refining. It is of paraffin base and varies in gravity from 25° to 50° Beaumé (0.9032 to 0.7778 sp. gr.), the heavier grades coming only from the southern end of the field. The price of the "Pennsylvania grade" oil is always high, ranging up to $2.50 per barrel. The average daily production of the wells is low, being 0.2 to 0.4 barrels in 1911. This field is almost completely developed except the portions in Kentucky and Tennessee, and even here recent prospecting has resulted negatively in a majority of cases.

Lima-Indiana field.—The Lima-Indiana field covers a considerable portion of northwestern Ohio and eastern Indiana. The oil is derived from the Ordovician, Silurian, and Carboniferous, largely from the Trenton limestone, the reservoir rock being porous dolomitic lenses or beds or sandstones. Favorable structures, such as half domes, terraces, etc., on the flanks of the Cincinnati uplift, usually harbor the commercial deposits. The oil is of paraffin base, varies in gravity from 30° to 35° Beaumé (0.8750 to 0.8484 sp. gr.), carries a little sulphur, and is utilized entirely for refining purposes. The average initial daily production of the wells up to 1911 was 15.5 barrels; the average daily production per well was 0.7 barrel for that year. This field also is practically outlined, although new pools are even yet being occasionally discovered.

Illinois field.—The Illinois field occupies a strip of territory along the La Salle anticline in the southeastern part of the State. It also extends a short distance into Indiana. The oil is derived largely from the Pennsylvanian and a little from the upper Mississippian (both Carboniferous), and occurs principally in well-defined sandstone horizons along the crest of the asymmetric La Salle anticline. Impregnation is governed locally by the lithology. A little of the oil comes from limestone. The oil is of paraffin base, although locally carrying some asphalt, ranges in gravity from 28° to 39° Beaumé (0.8860 to 0.8284 sp. gr.), and is used principally for refining purposes. The average initial daily production up to 1911 was 63 barrels; the average daily production of the individual wells for the same year was 4.2 barrels. With the exception of some possible territory in the western part of the State the Illinois productive area is well defined at the present time.

Mid-Continent field.—The Mid-Continent field comprises the pools in Oklahoma, southeastern Kansas, and northern Texas. The oil is secured from the sandstones of the Pennsylvania (Carboniferous) formations in domes, half domes or terraces, and local anticlines on the flanks of the great Ozark uplift. The oil is of paraffin

base, varying in gravity from 27° to 41° Beaumé (0.8917 to 0.8187 sp. gr.), and is used for refining. It is piped to the Gulf and also to Indiana and other eastern States. The development in this field has been phenomenal during the past few years, some of the pools being exceedingly productive. The average initial daily production of the wells in 1911 was 119 barrels; the average daily production 8.6 barrels. A fair percentage of the region embraced in this field yet remains to be prospected, the bulk of the untested land lying in Texas.

Gulf field.—The Gulf field includes the pools lying along the coastal plain of Louisiana and Texas. The oil occurs for the most part in domes or quaquaversals associated with salt and gypsum deposits. The age of the containing rocks ranges from Cretaceous to Quaternary. The reservoir rock is usually porous dolomitic limestone or sandstone. The oil of northern Louisiana occurs in Cretaceous and Eocene rocks along an uplift or fold. The oils of the Gulf field vary greatly in composition; those in the strictly coastal belt vary from 15° to 27.7° Beaumé (0.9655 to 0.8878 sp. gr.) and are of asphalt base; those of northern Louisiana vary from 25° to 43.6° Beaumé (0.9031 to 0.8065 sp. gr.) and are of paraffin base. Sulphur usually accompanies the heavy oil. The lighter oils are used for refining, the heavier for fuel. Some of the individual wells have been exceedingly productive, a daily flow of 75,000 barrels being recorded for one at least. The pools usually are quite short-lived. In 1911 the average initial daily flow for the Gulf coastal pools was 257 barrels; for northern Louisiana, 1,176 barrels; the daily average for the field, 60 barrels. Some territory still remains untested in this field.

Rocky Mountain field.—The Rocky Mountain field embraces pools in Wyoming and Colorado and as yet untested deposits in Utah and New Mexico. The oil occurs in beds of Carboniferous, Triassic (?), and Cretaceous age, nearly always in sandstone interbedded with shale, though occasionally in fracture zones. Typical dome structure is the most favorable location, but occasionally commercial deposits occupy monoclines or interrupted monoclines. The oils from the older formations vary in gravity from 18° to 24° Beaumé (0.9459 to 0.9091 sp. gr.), are of asphalt base, and are used largely for fuel; those from the Cretaceous vary from 32° to 48° Beaumé (0.8642 to 0.7865 sp. gr.), are of paraffin base, and are refined, yielding high percentages of gasoline, kerosene, and distillates. The productivity of individual wells usually is not large, the average daily yield per well being about 25 barrels in 1913. The potentialities of the Rocky Mountain field are not great, unless the extensive deposits of oil shale of northwestern Colorado and northeastern Utah are taken

into account. As these deposits will require a distillation process for the recovery of their oil contents, they are not included under the head of free oil deposits.

California field.—California is the greatest producer of petroleum of any State in the Union. It secures its oil from rocks of Cretaceous to late Tertiary age, the great bulk coming from the Miocene. Nearly every type of structure peculiar to the coast ranges yields commercial quantities of oil, anticlines, domes, plunging anticlines, monoclines, and fault zones being the principal sources. The reservoir rocks usually are sand and sandstone, though fracture joints in shale hold oil in at least one district. The oil is practically all of asphalt base, although paraffin up to 4 per cent is found in a little of the oil from the Cretaceous and Eocene. The oil varies in gravity from 12° to 35° Beaumé (0.9859 to 0.8484 sp. gr.), about 70 per cent of it being topped or refined. Much of the heavy oil is used for fuel and road dressing. The productivity of individual wells has reached as high as 58,000 barrels daily; the average daily production per well was 45.2 barrels in 1913. The oil districts of California are practically outlined to-day and little in the way of additional acreage is to be expected in the future.

Alaska field.—Small quantities of oil have been obtained from the Jurassic rocks of western Alaska and the lower Tertiary of eastern Alaska. The oil occurs in sandstone along well-defined and sometimes faulted anticlines. The oil varies in gravity from 39° to 45.9° Beaumé (0.8284 to 0.7958 sp. gr.) and is of an excellent refining grade. The wells so far drilled are small producers. The commercial productivity of the Alaskan deposits yet remains to be proven.

Other fields.—In addition to the States mentioned as occupying the above fields, oil occurs in small quantities in Michigan (a continuation of the Petroleo, Canada, field) and Missouri (a continuation of the Oklahoma conditions). These States and Alaska together produced but 7,792 barrels in 1914. Alabama and Mississippi also are said to have possibilities.

IMPORTANCE OF THE UNITED STATES AS COMPARED WITH OTHER COUNTRIES.

The following table, compiled under the supervision of J. D. Northrop, of the United States Geological Survey,[1] giving the production of crude petroleum in 1914 and from 1857 to 1914, in barrels, illustrates the relative importance of the various oil-producing countries of the world.

[1] Mining and Scientific Press, Aug. 14, 1915, p. 248.

TABLE I.—*World's production of crude petroleum in 1914 and 1857 to 1914, with percentage of production by countries, in barrels of 42 gallons.*

Country.	1914		1857-1914	
	Production.	Per cent.	Production.	Per cent.
United States	265,762,535	66.36	3,335,457,140	59.63
Russia	67,020,522	16.74	1,622,233,545	29.00
Mexico	21,188,427	5.29	90,339,809	1.62
Roumania	12,826,579	3.20	117,952,474	2.11
Dutch East Indies	[1] 12,705,208	3.17	138,278,399	2.47
India	[2] 8,000,000	2.00	73,979,919	1.32
Galicia	[2] 5,033,350	1.26	131,873,601	2.36
Japan	[3] 2,738,378	.68	27,051,158	.48
Peru	1,917,802	.48	14,306,972	.26
Germany	[2] 995,764	.25	12,065,569	.22
Egypt	777,038	.19	1,088,728	.02
Trinidad	643,533	.16	2,069,430	.04
Canada	214,805	.05	23,490,610	.42
Italy	39,548	.01	802,229	.01
Other countries	[4] 620,000	.16	1,322,000	.02
Total	400,483,489	100.00	5,590,202,936	100.00

[1] Includes British Borneo.
[2] Estimated.
[3] Includes Formosa.
[4] Includes 600,000 barrels produced in Argentina.

The relative importance of the States in the Union is shown in the accompanying table, which gives the marketed production for the year 1914. In the case of two of the States at least, the marketed production is below the estimated production, the discrepancy being accounted for by oil put in storage. The actual production of California was probably around 103,000,000 barrels, with possibly 7,000,000 barrels "shut in," which might have been produced. The estimated production of Oklahoma was 98,000,000 barrels.

TABLE II.—*Production of petroleum in the United States, by States, in 1914 and 1857 to 1914, in barrels of 42 gallons.*

	1914	1857-1914
Alaska	(1)	....
California	99,775,327	741,273,539
Colorado	222,773	10,649,143
Illinois	21,919,749	222,326,614
Indiana	1,335,456	102,823,798
Kansas	3,103,585	28,547,074
Kentucky	502,441	9,095,970
Louisiana	14,309,435	89,805,433
Michigan	(1)	72,712
Missouri	(1)	....
New Mexico	....	....
New York	938,974	(2)
Ohio	8,536,352	432,762,004
Oklahoma	73,631,724	461,832,466
Pennsylvania	8,170,335	754,190,215
Texas	20,068,184	203,799,331
West Virginia	9,680,033	260,232,815
Wyoming	3,560,375	7,904,944
Other	7,792	....
Total	265,762,535	3,335,457,130

[1] Included in "Other."
[2] Included in Pennsylvania.

FACTORS GOVERNING THE PRODUCTION OF PETROLEUM.

Before entering into a discussion of the probable future production of petroleum in the United States, it will be well to outline the various factors which govern this production. These factors may be divided into two groups, natural and artificial.

A. NATURAL FACTORS.

1. *Pressure.*—The pressure exerted on the oil in its underground reservoir may be hydrostatic, hydraulic, or gas; it may be coextensive with the field or pool, in which case it is called "field pressure," or it may be exceedingly local in extent, when it is called "local" or "well pressure." Pressure in oil wells varies from 0 to over 2,000 pounds per square inch, usually declining as the field or well grows old. Other things being equal, the production varies with the pressure.

2. *Viscosity.*—Production varies inversely with the viscosity, and since the viscosity in general increases with the specific gravity (increases inversely with the Beaumé degrees) it may be said that, other conditions being equal, the production varies inversely with the specific gravity of the oil. Natural petroleums vary from substances as fluid as water (low viscosity) to those having the consistency of "cold molasses" (high viscosity), or even to those possessing the properties of solids.

3. *Thickness and extent of reservoir rocks.*—The production varies with the thickness and extent of the reservoir rock. The thickness of the pay streaks may vary from 2 feet, as in some fields of the eastern United States, to over 200 feet, as in some California fields. The lateral extent of the layer or lens may be from a few feet to several miles.

4. *Porosity of reservoir rocks.*—Production varies inversely with the porosity within certain limits. In uniformly grained rocks the coarser the grain of the reservoir the less is the actual porosity; but the larger the size of the interstices the less is the friction surface per unit of oil. Therefore, coarse sediments are really less porous and consequently hold less oil, but they give it up more readily than fine sediments and usually give a greater ultimate yield per unit of volume. Reservoir rocks may be fine shale to the coarsest conglomerates, or porous or cavernous dolomites or limestones. Fracture or fault zones also may act as reservoirs. The world's maximum producers obtain their oil from cavernous limestones or dolomites; the steadiest and longest-lived wells are in medium-grained sand.

5. *Structure of reservoir rocks.*—Structure usually has a profound influence on oil accumulation and production, the most advantageous positions being in the crests of domes or anticlines, or on the flanks of sealed or terraced monoclines. Lithology or other causes may locally produce exceptions to all rules of accumulation.

B. ARTIFICIAL FACTORS.

1. *Price of oil.*—The price of oil is the dominant factor governing the production of oil, especially as it relates to groups of wells, fields,

districts, or States. The price may vary from 10 to 15 cents a barrel at the well, as at certain periods in the history of the Mexican or California fields, or it may range up to $2.50 per barrel, and in exceptional cases much higher, when the demand is great and the supply limited. Price of oil largely affects the other artificial factors, which may be summarized as follows:

2. *Depth of wells and time required to drill.*—Production may be accelerated or retarded by the time required to drill wells. In some places wells can be put down in a week or 10 days; elsewhere it may take from one to two years to finish a well. In a shallow well district production can be increased quickly by a vigorous drilling program; in deep well areas much time and money may be necessary to increase or even sustain production.

3. *Distance separating wells.*—Within a certain underground reservoir, the quantity of oil that ultimately can be recovered and the rapidity with which it may be produced are largely dependent on the distance separating the individual wells. The thicker the wells the quicker the recovery of the oil and the greater the expense of recovery. Wells may be spaced 25 feet apart or as near together as the derricks will stand, as in the congested Spindle-top field of Texas, or they may be separated by a distance of one-fourth mile or more. Ownership of property often determines the spacing of the wells, many small tracts under separate ownership tending toward congestion of development and rapidity of recovery. Conservation is best attained by single ownership of large bodies of land, so that development will be determined by the principle of recovering the oil at the least possible expense, that is, with the least number of wells.

4. *Condition of well, pump, etc.*—The condition of the well, pump, and other physical properties involved in the winning of the oil greatly influences the production. Clean wells, efficient pumps, and energetic employees tend toward maximum production; sanded up or improperly perforated wells, leaky pumps, and inexperienced or careless employees militate against successful operation.

5. *Discovery of new fields.*—The discovery of new fields is a most potent factor in oil production. The search for new fields is stimulated by high prices; their discovery usually results in a flush yield and a lowering of the price. Obviously, each new field raises the normal production to be expected from any district or State, and it is this factor of new territory which lends so much uncertainty to the oil business.

6. *Distance from market.*—The distance from market of any field or group of wells often determines the rate of development and consequent production. Those fields nearest to market or favorable

transportation facilities are usually quickly developed to their maximum capacity, while fields farther away are often left for years without even being adequately prospected.

7. *Improvements in development and recovery methods.*—New methods of drilling and increasingly efficient methods of recovery are favorably affecting production in many fields. The most important advance in recent years has been along the line of increased use of compressed air in the recovery of oil, especially in California and Pennsylvania.

8. *Water complications.*—"Water troubles" may be either natural or a combination of natural conditions and human carelessness or ignorance. Water causes the final ruin of practically all oil fields; it is the omnipresent and greatest menace of the producing fields. In most cases water troubles are inexcusable. Their results almost always are negative and sometimes irremediable.

Oil in most fields of the United States and, in fact, throughout the world, occurs in inclined or sloping beds of sand or other porous rock, and these oil zones usually are overlain and underlain by water sands or zones which are separated from the oil zones by impervious clay, shale, or other strata. In these two cases the water is extraneous to the oil sands. These waters are called "top" and "bottom" waters, in accordance with their occurrence, respectively, above or below the oil zones. In a properly finished well the "top" water is cased off or cemented off before the well is drilled into the oil sand. The "bottom" water never is drilled into except by accident, in which event it is plugged off. With the "top" water shut off and the "bottom" water untouched, the oil is produced practically free from water. Water, being heavier than oil and often also under a greater hydrostatic pressure, will replace part or all of the oil at the point of ingress into the well if it is allowed to reach the oil sand. In this way it replaces the oil, in whole or in part, and thus lessens the amount of oil produced and increases its cost of recovery. Water also occurs indigenous to the oil sands in certain fields, but in this case it does not at first occupy the same part of the stratum as that occupied by the oil, but lies in the lower or "down-slope" portion of the sand, and the line marking the junction of the oil in the "up-slope" part of the bed and the water in the "down slope" part determines the limits of the productive territory. The water under these conditions is called "edge" water. Upon exhaustion of the oil by flowing or pumping, the "edge" water, through hydrostatic or other pressure, usually "follows up" and replaces the oil. The appearance of the originally extraneous "top" water or "bottom" water in a well indicates a failure to exclude the water properly by the manipulation of casing, cement, or plugs. Such a condition usually can be remedied and the offending fluid kept out of the oil sand,

although what has come in already may sometimes remain in the oil to a greater or less extent. The appearance of "edge" water in a well is another matter, for here the oil has been permanently replaced by the water, and, so far as the affected sand is concerned, the well can be considered as no longer productive. "Edge" water sometimes appears in a well in some particular sand, while other producing sands are free from water. In this instance, the "edge" water sand is abandoned and cased off and the production continued from the other sands.

Most of the water troubles are due to a failure to shut off the "top" water in the process of drilling. Wells, properties, and entire fields have been seriously damaged or entirely ruined by the water, sometimes from only a few offending wells. This factor of water is, therefore, one of the most potent in oil production and at the same time the most uncertain.

METHODS OF ESTIMATING FUTURE SUPPLY.

Two methods of estimating the future production or supply of oil in any area or field are in use, one known as the saturation method, the other, the production curve method.

SATURATION METHOD.[1]

The saturation method of computation involves finding the cubical contents of the reservoir, determining the degree of porosity of the volume, and then estimating the total, available, and net supply of oil contained under the area in question. By total supply is meant the total quantity of oil in the reservoir; by available supply is meant the quantity that theoretically can be recovered with ordinary methods in vogue; net supply is the quantity marketed after deducting for fuel used in development and operation, leakage, and other losses.

Total supply depends on the volume and porosity of the reservoir and on the volume of free gas and of water which are included in the oil. The first factor usually can be approximated by taking the area involved and multiplying by the average thickness of the oil sand or zone. The porosity can be approximated from outcrop samples or drilling samples of the reservoir. Gas and water contents are uncertain, but in most instances can be disregarded for rough approximations. Gas usually is in solution and the water only in the outlying edges of the oil pools. Available saturation may range from 0 to, possibly, 80 per cent, depending largely on the gas pressure and other factors, such as grain of reservoir, coherency, etc. From 40 to 60 per cent of the total quantity ordinarily is recoverable. Of

[1] This method is described by Chester W. Washburne, Bull. A. I. M. E., No. 98, February, 1915, pp. 469–471.

this quantity possibly 10 per cent to 15 per cent is lost in production or used for fuel, so that of the total supply but 34 per cent to 54 per cent ordinarily is marketed. Many years may be required to make even this recovery.

It is the writer's belief that estimates based on the saturation method are much less reliable and satisfactory than those worked out through the production-curve method, but the former must be used for new or poorly developed fields and will be briefly described.

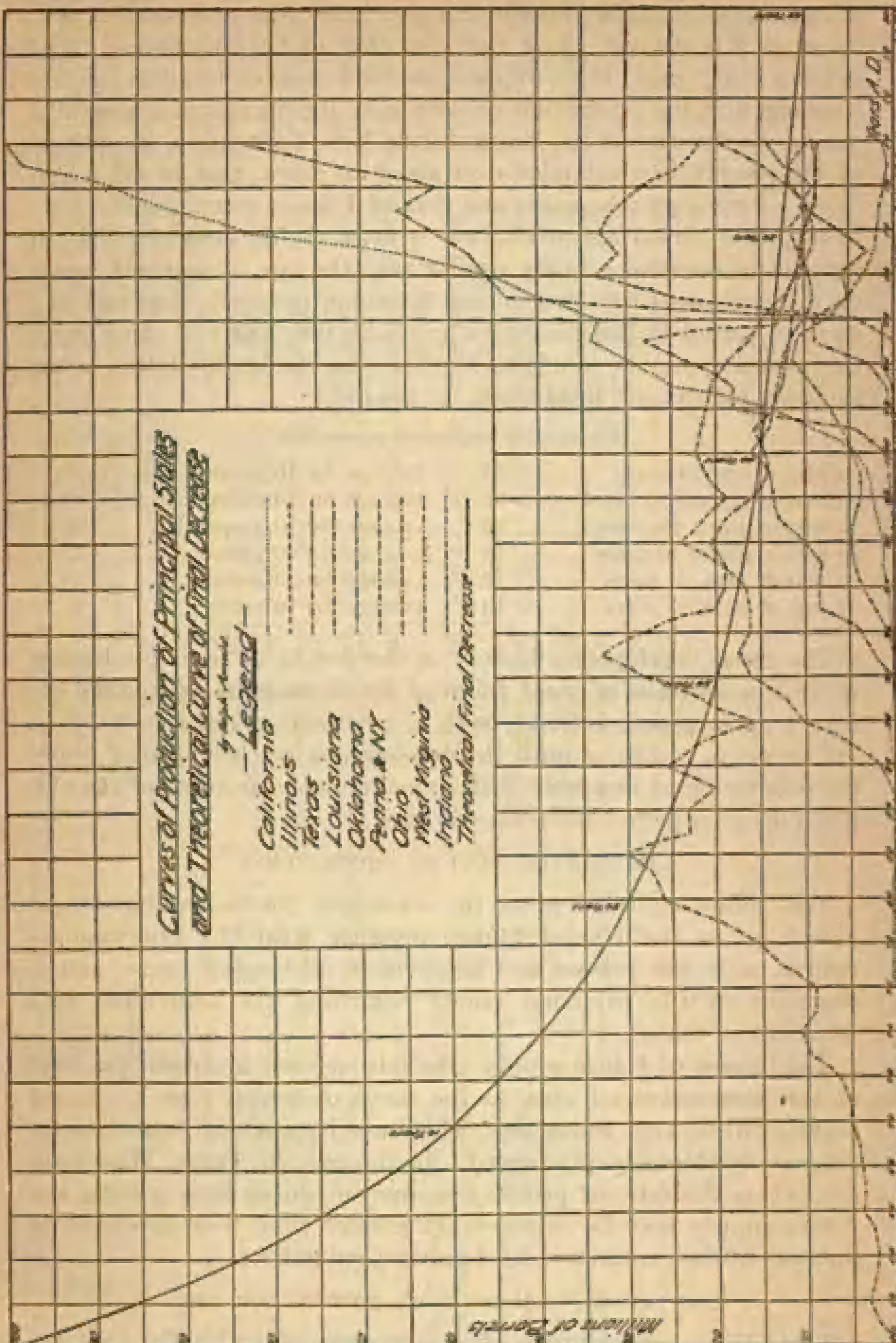
The thickness of producing oil sands or oil zones varies from 2 feet in the Illinois field to over 200 feet in the California field. Total supply or saturation as marked by the porosity varies from a trace, in sands, up to 50 per cent in some exceedingly porous diatomaceous shale from California. Between 5 and 15 per cent is the average for sands, some, however, going as high as 30 per cent. An acre of ground covered with oil a foot deep (1 acre-foot) contains 7,758 barrels. This would be complete saturation for the 43,560 cubic feet. Assuming an average of 10 per cent saturation would give 775.8 barrels per acre-foot for normal conditions. On this basis a 5-foot sand would contain 3,879 barrels per acre, and a 50-foot sand 38,790 barrels. Actual yields of over 100,000 barrels per acre are known. Estimates of the average production per acre for the various States are given in Table III. Most of these figures are based primarily on the production-curve method, but a few are based on or checked by the saturation method.

PRODUCTION-CURVE METHOD.

General statement.—Estimating future production or supply by a plotting of hypothetical curves, based on actual figures in well-known areas or fields, is the safest method, as it involves factors which it is possible to obtain. Another thing in its favor from the standpoint of the producer and marketer of oil is that it is based on and has to do with actual "net" oil figures, instead of theoretical quantities.

Basis of theoretical curve.—The theoretical curve shown in the diagram accompanying this article is based primarily on the yearly total production figures of New York and Pennsylvania. These figures cover a period of productivity of 54 years, longer by far than that of any other field in the United States. Furthermore, over this period this field has been subject to all of the vicissitudes from both natural and artificial causes that beset oil fields in general. The area involved in the Pennsylvania and New York field is greater than that in any other field in the United States, which is still another reason why the result should be conservative.

The interesting part of the production curve is that following the period of maximum yield. In some instances it is fairly safe to


Curves of Production of Principal States
and Theoretical Curve of Final Decrease
— Legend —
California
Illinois
Texas
Louisiana
Oklahoma
Penna & N.Y.
Ohio
West Virginia
Indiana
Theoretical Final Decrease
Millions of Barrels
Years A.D.

predict just when this period is reached, although usually a great divergence of opinion prevails, due to whether the prophet is a producer or a consumer. As a rule, the crest of the production curve is not a sharp peak, but is represented by a more or less wavy dome, showing that the production remains near the maximum for several years. In the case of the Pennsylvania-New York curve, the period of high production extended over about 10 years; that of Ohio and West Virginia over 8 years; and that of Illinois over 2 years. Following this period the production is more or less irregular, but in general decreases at a fairly regular rate, the rate of decrease, based on the previous year's production, becoming gradually less and less as is indicated in the theoretical curve in the diagram. In figures this decrease may be tabulated thus, the basis of computation being the maximum yearly production for the field:

Per cent of maximum production.

At end of first 10 years	50	Average for 10 years	75
At end of second 10 years	30	Average for 10 years	40
At end of third 10 years	20	Average for 10 years	25
At end of fourth 10 years	15	Average for 10 years	17.5
At end of fifth 10 years	12.5	Average for 10 years	13.75
At end of sixth 10 years	10	Average for 10 years	11.25

The usual development history in the period of high production is, first, a decrease of yield followed by increase in price, then renewed development activity, with a resultant increase in yield, a fall in price, and so on until the development reaches a point where the production of new wells fails to make up the decrease of the old, when the final period of decrease begins.

ESTIMATED FUTURE PRODUCTION.

The following table gives the estimated future production of petroleum in the United States, together with the approximate figures as to the proven and prospective oil-bearing areas, and a summary of the principal points regarding the occurrence and character of the oil.

The figures of future supply take into account a certain per cent of the prospective oil area, as the curve on which they are based pertains to an area where new fields have been added from time to time as development progressed. In the case of Texas, Wyoming, etc., where the ratio of prospective area to proven area is high, the future supply may be considerably greater than that predicted if the bulk of the prospective land proves productive.

COMPARISON WITH DR. DAY'S FIGURES FOR 1908.

Table IV is a comparison of the estimates given by Dr. Day for 1908 with those by the writer for 1915. They are here presented by fields in order to correspond with Dr. Day's divisions.

TABLE III.—*Past and estimated future production of petroleum in the United States.*

State.	Age of containing rocks.	Base.	Quality of oil.	Production for 1914.	Total production including 1914.	Probable future supply.	Proven area.	Prospective area.	Average production per acre.	Per cent exhaustion.
Alaska	East-Lower Tertiary; West-Jurassic.	Paraffin	30°–45.9° B.—0.8284–0.7958			10,000,000		15	1,000	0
California	Cretaceous; Tertiary	Asphalt	12°–35° B.— .9859– .8484	99,775,327	711,273,559	2,300,000,000	156	40	30,000	24
Colorado	Pierre-Cretaceous	Paraffin	35°–44° B.— .8333– .8045	222,773	10,649,143	21,000,000	17	33	1,000	33½
Illinois	Mississippian - Pennsylvanian.	do.	28°–39° B.— .8860– .8284	21,919,749	202,326,616	400,000,000	400	100	2,500	30+
Indiana	East - Ordovician (Trenton) West - Pennsylvanian.	do	30°–35° B.— .8750– .8484	1,335,456	102,823,798	20,000,000	500	100	400	83+
Kansas	Pennsylvanian	Paraffin-asphalt.	27°–35° B.— .8917– .8333	3,103,585	28,547,674	40,000,000	70	30	1,500	42
Kentucky, Tennessee.	Mississippian	Paraffin	25°–43° B.— .9032– .8092	502,441	9,096,970	10,000,000	100	100	300	47
Louisiana	Cretaceous - Quaternary: Cretaceous-Eocene.	do	21°–41° B.— .9271– .8187	14,309,435	89,896,433	170,000,000	87	40	4,300	34
Michigan, Missouri	Carboniferous	do	30° B.— .8750	7,792	73,712	100,000	1			58
New Mexico	Carboniferous - Cretaceous.							25		
New York, Pennsylvania.	Devonian - Carboniferous	Paraffin	25°–50° B.— .9032– .7778	9,100,309	734,180,215	133,000,000	1,400	100	1,000	85
Ohio, east and west	Ordovician - Carboniferous	do	35°–47° B.— .8484– .7900	8,536,352	432,762,004	205,000,000	115 535	50	1,500	67
Oklahoma	Pennsylvanian	do	32°–41° B.— .8641– .8187	73,631,724	401,823,466	1,845,000,000	297	73	10,000	22
Texas	Pennsylvanian, Cretaceous-Quaternary.	Asphalt and paraffin.	15°–38° B.— .9655– .8333	20,068,184	203,799,381	400,000,000	50	150	17,000	33+
Utah			22°–40° B.— .9210– .8235					20		
West Virginia	Devonian - Carboniferous		27°–52° B.— .8917– .7612	9,680,033	260,232,815	207,000,000	350	50	2,000	55+
Wyoming	Carboniferous - Cretaceous.	Asphalt-paraffin.	15°–48° B.— .9459– .7865	3,560,375	7,904,944	300,000,000	31	20	15,000	2
Total				265,762,535	3,335,457,130	5,763,100,000	4,100	946		36

TABLE IV.—*Estimated total production of the United States, by fields.*

	Arnold—1915.		Day—1908.	
	Per cent.	Total production.	Minimum.	Maximum.
Appalachian	19	1,729,800,000	2,000,000,000	5,000,000,000
Lima-Indiana	4	406,298,000	1,000,000,000	3,000,000,000
Illinois	7	632,327,000	350,000,000	1,000,000,000
Mid-Continent	26	2,340,000,000	400,000,000	1,000,000,000
Gulf	6	592,896,433	250,000,000	1,000,000,000
California	33	41,273,000	5,000,000,000	8,500,000,000
Minor fields	5	1,349,966,707	1,000,000,000	5,000,000,000
Total	100	9,008,557,140	10,000,000,000	24,500,000,000

Comparing the writer's estimates with those of Dr. Day, it is at once apparent that the estimates for the older eastern fields have been reduced while those for the western fields have been increased. This is especially true for the Mid-Continent field, in which there was little development at the time Dr. Day's figures were compiled. In the case of California [1] it has been found that the available saturation is less than was expected during the early history of the field. At the time the first estimates were made the field gas pressure was high and water trouble had not become serious. With the lapse of time it has become evident that a reduced gas pressure and water infiltration necessitate materially cutting the original figures.

At the present rate of consumption of approximately 265,000,000 barrels per year, an estimated supply of 5,763,100,000 barrels would last only, approximately, 22 years. However, as the total production of the United States will gradually decrease from year to year, it is believed that the total available supply will spread out over a period of from 50 to 75 years. The price of oil, which now ranges from 40 cents to $2 per barrel (average, 95 cents), depending on the locality and grade of the product, probably will increase to figures approximating $1 per barrel for fuel oil and possibly $5 or more for the lighter grades. All other factors being equal, a barrel of fuel oil as compared with coal on the Pacific coast is worth to-day 93 cents. Even were oil to be used only as a fuel, the tendency would be for it to rise in price until it reached a point set by the value of coal in the same regions. As oil has so many points in its favor, as regards ease of handling, cleanliness, etc., it is quite evident that eventually it will be sold at a higher price than is warranted by its heat value as compared with that of coal.

Before the free natural petroleum in the earth is exhausted the oil shales of Colorado, Utah, California, and other States will have begun to be utilized as a source of petroleum. Also artificial oil made from animal and vegetable waste probably will be available to take its place. Even at the present time the necessities of war have led certain of the European governments to utilize various substitutes for petroleum and its derivatives, the substitutes in general being made from organic substances.

In conclusion, the writer might repeat what often has been pointed out by conservationists, that oil as far as possible should be used for those purposes for which we have no other substitute, namely, for lubricants, refined derivatives, etc., and not for fuel. If used for fuel, it should not be in connection with the wasteful steam engine, but in the Diesel engine and similar types, which are so much more efficient that their use doubtless will become more and more general as time goes on.

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Mid-Continent	26	2,346,000,000	400,000,000	1,000,000,000
Gulf	6	592,895,433	250,000,000	1,000,000,000
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THE OUTLOOK FOR IRON.[1]

By Prof. James Furman Kemp,
Columbia University.

The close of the nineteenth century produced an attitude of mind in many students of national affairs akin to that of a merchant who balances his books at the end of a twelvemonth. When the results of a year's business have been demonstrated, the merchant decides on his plans and policies for the future. He makes a reliable estimate of his resources and learns his possibilities and his limitations. As a nation which looked over a hundred years instead of one year, we were in much the same position when the twentieth century opened.

From small beginnings, all manner of industries had reached an impressive development. Some employed materials which were constantly reproduced either by plants or animals, and which, by improved methods, could be increased in amount; but other industries were rapidly drawing upon fixed reserves which could not be renewed. We naturally began to forecast the future and, with a look ahead, to infer the course of events in the century then opening. Among the industries, that of mining came in for special attention. It is a very great one in this country, and it is distinctive in that it destroys its raw materials in utilizing them. Forests, crops and live stock all grow again. Ore and coal mined are gone forever. Not unnaturally, in a fundamental industry such as iron mining—one on which so many others rest,—people vitally interested began to raise the question of reserve for the future and to wonder in what position the industry would find itself fifty or a hundred years later. We are not surprised, therefore, to note that open expression was given to feelings of apprehension, nor that some prophecies were made whose restatement now possesses much interest. Not alone, however, in our own country were these apprehensions felt. Abroad, they likewise found expression, especially in England, whose people had been roused for years regarding the future of their coal fields.

In October, 1902, Mr. Andrew Carnegie, one of our most distinguished ironmasters, was installed as rector of the University of

[1] Reprinted by permission from Contributions from the Geological Department, Columbia University, Vol. 27, No. 1.

St. Andrews, Scotland. He delivered a very interesting address in which he stated that if the rate of consumption of iron ore in the United States did not greatly increase, we would have a supply of first-class iron ore for only 60 or 70 years and of second-class for 30 years longer. Mr. Carnegie estimated our demonstrated store of unmined ore at 1,000,000,000 tons. The consumption, at that time, was between twenty-five and thirty millions of tons annually. All persons well informed upon mining matters would infer that the mining of a billion tons, now demonstrated, would reveal appreciably more; and while a billion tons divided by 25 gives a life of 40 years, 60 or 70 years was a not unreasonable figure. Yet this period is a relatively short one and the forecast justifies anxiety. Since Mr. Carnegie's address was delivered, the annual output of ore has doubled, and, unless relieved by other considerations, whatever apprehensions were justified then are twice as emphatic now.

In 1895, from three different spokesmen came prophecies similar to those of Mr. Carnegie. Sir Robert A. Hadfield, whose words regarding the iron and steel industry should carry as great weight as any man's, in a presidential address to the British Iron and Steel Institute[1] forecasts the call of the world's furnaces upon the mines at the outset of the new century, and upon the basis of known reserves also gave good ground for apprehension. In the same year, the late Prof. Törnebohm, long the chief of the Swedish Geological Survey and with special experience in iron ores, made a report to the Parliament of Sweden, based on a visit to this country.[2] At this time the Swedish Government was actively sharing in the development of the great bodies of iron ore in Lapland, far within the Polar Circle. The importance of knowing the part which they might play in the world's iron industry of the future was great, and the determination of the limits of annual output was a matter in which the Swedish authorities felt a lively interest.

Prof. Törnebohm credited the Mesabi Range with half a billion tons; the other Lake Superior ranges, collectively, with as much more; and the Eastern brown hematites with 60,000,000. This total of a little over a billion tons gave cause for anxiety, since the output in 1905 of American mines had risen beyond forty millions, and a life of 25 years was thus indicated. But, of course, a moment's reflection shows that the estimates are incomplete, since the Clinton ores of the East, and especially of Alabama, are omitted entirely.

In the same year, 1905, the late Prof. N. S. Shaler sought to rouse his countrymen to an appreciation of the situation with regard to the mining industry in a paper of a popular nature on "The Ex-

[1] Proceedings, 1905, I., 27, and especially 58–60.
[2] Reprinted in the Iron Age, Nov. 2, 1905.

haustion of the World's Supply of Metals."[1] Prof. Shaler, in general terms, considers the supply of ores of all sorts remaining to us as, roughly, twenty times the amount already mined. He thinks another century will exhaust the European supplies of iron ore. The best place for the iron industry is in the Mississippi Valley, and the ores tributary to it are passed in review without definite figures, except for Alabama, to whose Clinton red hematites a life of 50 years is assigned.

Other papers preceded, accompanied or followed the four specially cited and of these a list is given at the close of this contribution. They can not all be mentioned now, and the ones briefly reviewed will suffice to show the apprehensive state of the public mind, here and elsewhere, from 10 to 15 years ago.

As a symptom of the widespread interest and as a natural step to prevent waste and to maintain as long as possible the material supports of industries, the conservation movement sprang up in this country. It has taken form in annual conventions and discussions, and has been influential in matters of legislation. Outside the American boundaries, similar steps have been taken. Reports of the Canadian Conservation Commission regularly reach us.

In connection with conservation in general, iron ore has been one of the chief subjects to be considered, and we are not surprised to find our Swedish colleagues, as soon as they were assured at the International Geological Congress held in Mexico City, in 1906, that their invitation for the meeting of 1910 would be accepted, began to plan a great work on the "Iron Ore Resources of the World." Iron mining is one of the chief, if not the chief, single industry in Sweden. The subject, therefore, possessed great local as well as international importance. The associated authors in all lands began to busy themselves at once with data and estimates of reserves. A year after the movement had been started by the Swedish committee and by its representative in this country, a special investigation of American iron ore reserves was also initiated under the United States Geological Survey with Dr. C. W. Hayes in charge of the collection of data. The result of these endeavors led to the preparation of as complete estimates as were practically possible.[2] They will be mentioned and utilized later on.

Before we can actually undertake a discussion of the future, we must have clearly before us several matters of vital import. We must know the large features of production in the United States as a whole and in the more important individual districts. We need to

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[1] International Quarterly, vol. 2, 230–247, 1905.

[2] C. W. Hayes, Bull. 394, U. S. G. S., 70–114, 1909.

briefly trace the progress of production during recent years. We need further to know what the general run of working percentages has been and to answer the questions: Is the yield per ton declining as the years pass, and are we content now to treat ores of lower grade than were our fathers? How do our ores compare in yield with those of foreign productive areas? We can not overlook the vital bearing of our supply of coking coal—a factor in present iron metallurgy not inferior to ore supply itself. We must consider sources of ore outside the United States and yet so situated as to contribute to our furnaces. We must also consider present, or reasonably certain future improvements in processes of smelting. No horoscope for the future can be cast without attaching due weight to all these factors.

The growth in the production of iron ore in the United States has been so great as to be the chief cause of anxiety for the future. The tabulation of a few figures, using a million long tons as the unit, will make the matter clear. Extended statistics are not necessary. I am extremely anxious that the great striking truths should not be lost in a maze of figures. The statistics are taken from the Mineral Resources of the United States Geological Survey. Detailed figures are not attainable for 1888 and earlier years, except in those in which a census was taken.

In the years before the Civil War the production was small, but shortly after peace was restored the Lake Superior mines began to assume greater and greater importance, and later Alabama developed its mining and smelting industry.

Statistics in millions of long tons.

	United States total.	Lake Superior.	Alabama.	Other Eastern States.	Western States.
1860	2.8	....	....	....	....
1870	3.8	0.8	....	....	....
1875	4.0	0.8	....	....	....
1880	7.1	1.9	0.17	5.2	0.00
1882	8.7	2.9	....	....	0.05
1884	7.7	2.5	....	....	0.02
1886	10.0	3.5	....	....	....
1888	12.0	5.0	....	....	0.08
1890	16.0	8.98	1.90	4.98	0.19
1892	16.2	9.50	2.31	4.24	0.15
1894	11.8	7.60	1.49	2.70	0.29
1896	16.0	10.50	2.04	3.10	0.26
1898	19.4	11.8	2.40	2.84	0.37
1900	27.5	20.60	2.73	3.75	0.54
1902	35.5	27.08	3.57	4.30	0.65
1904	27.6	20.30	3.70	3.28	0.36
1906	47.7	37.80	3.99	4.91	0.80
1908	35.0	28.10	3.70	3.50	0.57
1910	56.9	46.30	4.80	4.80	0.80
1912	55.1	46.40	4.60	3.10	0.90
1914	42.0	32.91	....	....	....

GENERAL PROGRESS OF PRODUCTION.

By these figures a modest but steady growth in the production of iron ore is shown up to 1884. A marked increase then developed, which subsequent figures will show was chiefly due to the entrance of the Gogebic and Vermilion Ranges. A rapid growth followed to 1890; and then production held steady, or, as in 1894, temporarily dropped back during panic times. Following 1896, the growth was very marked and was chiefly due to the Mesabi Range. Hard times checked it in 1904, in 1908, and again in 1914. No industry is more sympathetic with general business conditions than is the production of iron and steel.

The figures also show that the great increase in output is due to the growth of the industry in the Lake Superior region. Without the contributions from the lake, the country as a whole would be back in the position which it occupied in 1886, with about 10,000,000 tons total production.

In general, if we look back to 1860 and take time by decades, we may say that to-day the production is twenty times what it was in 1860; fifteen times what it was in 1870; eight times that of 1880; three and one-half times that of 1890; and twice that of 1900. We can not continue in the same ratio, but must ere long reach our zenith.

Production of the Lake Superior ranges in millions of long tons.

	Total United States.	Marquette.	Menominee.	Gogebic.	Vermilion.	Mesabi.	Cuyuna.
1870	3.8	0.85	0.0	0.0	0.0	0.0	
1875	4.0	0.88	0.0	0.0	0.0	0.0	
1880	7.1	1.38	0.52	0.0	0.0	0.0	
1882	8.7	1.83	1.14	0.0	0.0	0.0	
1884	7.7	1.56	0.89	0.001	0.06	0.0	
1886	10.0	1.63	0.88	0.75	0.30	0.0	
1888	12.0	1.92	1.19	1.43	0.51	0.0	
1890	16.0	2.86	2.27	2.91	0.89	0.0	
1892	16.2	2.84	2.40	3.06	1.23	0.03	
1894	11.8	1.93	1.25	1.52	1.05	1.91	
1896	16.0	2.42	1.76	2.10	1.30	3.08	
1898	19.4	2.99	2.27	2.55	1.12	4.83	
1900	27.5	3.94	3.68	3.10	1.67	8.16	
1902	35.5	3.73	4.42	3.68	2.06	13.08	
1904	27.6	2.46	2.87	2.13	1.05	11.67	
1906	47.7	4.07	4.96	3.48	1.79	23.56	
1908	35.9	3.31	2.90	3.24	0.92	17.79	
1910	56.8	4.63	4.98	4.74	1.39	30.57	
1912	55.1	3.54	4.46	3.92	1.45	32.60	
1914	42.0						0.37

A brief survey of the figures relating to the individual Lake Superior ranges will justify the following conclusions: The Marquette, Menominee, Gogebic, and Vermilion Ranges show a steady, normal increase in output, which is not startling nor one to cause, under ordinary circumstances, undue apprehension. Some signs of

declining output are manifest in the case of the Vermilion. The vast increase in the output of iron ore is due to the Mesabi Range, and from it in 1912 came nearly 60 per cent of the country's total. A marked decline in available supply from the Mesabi would bring about a greater falling off in ore supply than any possible increase in the other Lake Superior ranges, or than the present sources of supply from other mining districts, could make good. The Mesabi Range is the key to the maintenance of the domestic supply at its present grade, and when it declines we must appeal to foreign sources to keep the iron and steel industry in its present position.

YIELD OF THE ORES.

Conditions vary greatly in different parts of the country; at different times; with different ores; and with the entrance of new sources of supply. It is a general truth that the richest ores are obtained in the early days of mining. As time passes and the industry becomes firmly established, lower and lower grades come within the range of profit. Alabama Clinton ores gave much higher percentages when mined wholly above the permanent water level than they do now, when pursued below it. For many decades only lump ore, and much of that over 60 per cent iron, was produced by the magnetite mines of the eastern Adirondacks. To-day the greater portion of the ore goes first through a magnetic concentrator before it is shipped. In earliest years on Lake Superior hard, specular ore at 65 and above was sought. With improved facilities the grade came down to and below 60, but the soft ores found slight sale. Now the soft, earthy ores are the principal objects of mining, and the average grade is well down in the fifties. Important shipments of ore with percentages below 50 have been placed on the steamships.

In the summer of 1875, Prof. Albert H. Chester,[1] an experienced chemist, visited the Lake Superior region in the endeavor to secure average samples from the stock piles of the larger mines, all, of course, at that time in the Marquette range and shipping hard, specular ores. Four samples ranged from 61.01 to 66.83 and probably give a fair idea of the ore at that time sent away. Iron Mountain, Mo., ore ran 64.87; Lake Champlain magnetites, 56.01 to 62.68; Clinton, N. Y., fossil ore, 44.57, but yielded 43 in the furnace.

In September, 1890, Geo. W. Goetz[2] published a tabulated series of analyses from the four older Lake Superior ranges, which, when averaged, afford the following values. To give a correct average, the analysis of each mine's ore ought to be weighted with the output, and as the data for this calculation are not available, we must be

[1] Albert H. Chester, "On the Percentage of Iron in Certain Ores." Trans. Amer. Inst. Min. Eng., vol. 4, 212, 1875.

[2] Geo. W. Goetz, "Analyses of Lake Superior Iron Ores," Idem, vol. 19, 59, 1890.

content with the general significance of the results. On the whole, they supply us with trustworthy values.

Range.	No. of analyses.	Maximum.	Minimum.	Average.
Marquette	36	69.77	53.02	62.33
Menominee	23	65.20	52.18	60.00
Gogebic	21	65.43	54.05	62.09
Vermilion	8	67.54	60.20	64.50

These figures represent the good old times when specular ore was almost the only one produced and before the soft ores began to be a serious factor. They are, however, significant, in that customary working percentages, such as these, very probably were not without their influence in the estimates of the life of the ranges, as set forth by several of the writers whose opinions were cited in the introduction to this address.

Raphael Pumpelly, in connection with the summaries of the Tenth Census,[1] estimated on the best and most comprehensive data which we have ever had, the general average of iron ores for the United States at 51.22 per cent iron. The maximum average percentage among the States was that of Missouri, 60.01 (but Michigan had 59.57). The minimum was West Virginia, 37.92. Pennsylvania, the largest producer of ore in that year, gave 45.28. On the basis of ore production and pig-iron production, allowance being made for mill cinder, foreign ores, etc., John Birkinbine estimated for the Eleventh Census [2] an average of 51.27 for the country at large. An appreciable error crept in, however, in assuming pig iron to be entirely iron, whereas it is only about 95 per cent or less metallic iron. We can hardly compare this figure with the one given by Prof. Pumpelly which was based on actual analyses of samples. If we credit the 7,000,000 tons of pig iron, as used by Mr. Birkinbine, with 95 per cent iron, the average is 48.71, which indicates an appreciable falling off in yield in 10 years.

General estimates of average percentages which will be trustworthy are difficult to carry out on the basis of annual statistics of tons of ore and tons of pig iron. Foreign ores contribute to an appreciable degree, and their yield can only be estimated. Stocks of mined ore, stored at furnaces or mines at the end of a year, are naturally credited to that year, but they are not turned into pig iron until the following twelvemonth. Mill cinder is also a contributor of iron to the extent of a small percentage of the total. The data for all these corrections are not available for a long period of years, and, therefore, all could not be introduced in the following

[1] Tenth Census, vol. 15, 10, for the year 1879.

[2] Volume on Mineral Industries, p. 10.

estimates. The importations could, however, be deducted, and to them an average of 58 per cent iron has been arbitrarily assigned. The results obtained are so variable that their significance is rather one of degree than of actual individual accuracy. The statistics are chiefly taken from the Mineral Resources for 1910, page 76. Long tons are used.

	United States iron ore in thousands of long tons.	Imported ore in thousands of long tons.	Pig iron in thousands of long tons.	95 per cent pig iron, metallic iron, in thousands of long tons.	Iron in imported ores at 58 per cent in thousands of long tons.	Net iron.	Average per cent of ore.	Estimated by E. C. Eckel, "Iron Ores," page 358, 1914.
1870	3,832	....	1,678	1,594	....	1,594	41.6	....
1875	4,018	56.6	2,040	1,938	33	1,905	47.3	....
1880	7,120	493	3,802	3,612	286	3,326	46.7	....
1885	7,600	391	4,077	3,874	227	3,647	48.0	....
1890	[1] 16,302	1,247	9,203	8,653	723	7,930	48.6	56.50
1895	[1] 17,203	524	9,446	8,974	304	8,670	50.4	54.95
1900	[1] 26,722	898	13,789	13,100	521	12,579	47.1	51.55
1905	[1] 41,433	848	22,992	21,842	491	21,351	49.1	53.19
1910	[1] 55,246	2,591	27,304	25,939	1,501	24,438	44.2	49.42
1912	[1] 58,031	2,104	29,727	28,241	1,220	27,021	46.5	51.46

[1] These totals are the apparent iron ore consumptions as given in the Mineral Resources, United States Geological Survey, for 1912, p. 162. They differ from the totals of production in the previous tables because corrected for unsmelted stocks, exports, and zinc residuum. No correction is made for mill cinder.

The variations shown above are so pronounced as to cast some doubt upon the accuracy of the individual percentages, but we may have some confidence in the general tendencies shown. We can not but be impressed with the apparent practice of the mining companies of using lower grade ore in good times, as shown by high production, and saving higher-grade ores for bad years. So far as recent years are concerned, we can only say that the general grade has declined, although it does not appear to be as low as it was in 1870, when the brown ores of the East were so large a factor in production. It must be to-day well below 50 per cent.

In the last column, and for the years beginning with 1890, are given calculations of average yield, prepared by E. C. Eckel in his valuable manual on "Iron Ores," published in 1914. The same figures for apparent iron ore consumption have been used as in the calculations given in the first column of the present table; that is, the total annual production has been increased by imports and by zinc residuum (i. e., used for spiegeleisen by the New Jersey Zinc Co.), and diminished by exports and by stocks on hand at the close of the year. The zinc residuum is only 0.2 to 0.4 per cent of the total and makes little difference. But a decided difference arises in calculating the yield of American ores if one assumes that pig iron is pure iron, and lets the much richer importations of foreign ores enter into the calculation. These last two elements in the problem explain the wide divergence in percentages of from 4 to nearly 8 per cent between the average values given in this paper and those

quoted by Mr. Eckel. Both calculations depart from the truth in so far as mill cinder, blue billy, scrap iron, etc., enter into the problem, since no account has been made of them. Of course, there is also a slight loss of iron in blast-furnace cinder.

The great importance of the decline in yield is the vastly increased amount of reserves which are thereby brought within the range of mining. As the average may still further decline until it reaches, say, 35 per cent, the reserves, as figures to be given later will show, become enormous. Thirty-five per cent, however, is by no means an unreasonable figure for the general yield of the Jurassic ores in the Lorraine and Luxembourg districts, which so largely supply Belgian, French, and German furnaces. The same statement will apply to the Cleveland district in England. The great reserves of 35 per cent ore in the Lake Superior district are, however, highly siliceous, whereas the Jurassic ores are basic. In Silesia, in southeastern Germany, even lower percentages are not esteemed beyond the possibilities. Thirty-five per cent is therefore a not unreasonable figure to consider, when a long look ahead is taken. On the other hand, in comparing the yield of the ores in different lands, a distinction should be made between exporting and smelting countries. Exporting countries necessarily must furnish high-grade ore, so as to meet freight charges incident to long transportation.

ESTIMATES OF RESERVES.

Since 1905, several estimates of reserves have been made, of which condensed summaries may be cited.[1] The amounts are in millions of long tons.

1905. Törnebohm:	
Lake Superior	1,000
Alabama	60
Elsewhere	40
	1,000
1907. E. C. Eckel:	
Lake Superior	1,500-2,000
Alabama red ore	1,000
Alabama brown ore	75
Georgia red ore	200
Georgia brown ore	125
Tennessee red ore	600
Tennessee brown ore	225
Virginia red ore	50
Virginia brown ore	300
	4,075-4,575

Southern reserves for the remote future were estimated at 10,000 million tons.

[1] The figures as given for Törnebohm, Eckel and Butler-Birkinbine are cited from E. C. Eckel, "Iron Ores," 341–351, 1914.

1909. Butler-Birkinbine:

Lake Superior	1,618
Southern States	1,814.9
New York	750
New Jersey	135
Pennsylvania	45
Rocky Mountain region	100
	4,462.9

1911. Minnesota-Michigan Tax Commission, J. R. Finlay, engineer:

Minnesota and Michigan	1,584

1912. E. C. Eckel:

Lake Superior	2,000–2,500
Northeastern	300– 600
Western	300– 700
Birmingham	1,500–2,000
Texas	600–1,000
Other Southern States	500– 750
	5,200–7,550

The most complete of all the estimates is that of Dr. C. W. Hayes in Bulletin 394 of the United States Geological Survey, 1909. The estimates are divided into two classes of ores; first, those available under present conditions; and second, those which come within reasonable possibilities of utilization for the future. The statistics are given in long tons in millions and decimals of a million.

Districts.	Magnetite.	Specular and red hematite.	Clinton ore.	Brown ore.	Carbonate ore.	Total.
Available ores:						
Northeastern	160.0	2.0	35.0	11.0		208.0
Southeastern	12.5	8.0	463.5	54.4		538.4
Lake Superior		3,500.0	10.0			3,510.0
Miss. Valley		15.0		300.0		315.0
Rocky Mountains	51.5	4.3		2.0		57.8
Pacific Slope	68.9					68.9
Total	292.9	3,529.3	508.5	367.4		4,698.1
Titaniferous magnetite considered available by Dr. Hayes						90.0
						4,788.1
Not available ores:						
Northeastern	211.5	2.0	620.0	13.5	248	1,095.0
Southeastern	23.0	53.0	970.5	168.0	62	1,276.5
Lake Superior	4,525.0	67,475.0	30.0			72,030.0
Mississippi Valley		10.0		560.0		570.0
Rocky Mountains	116.9	2.1		1.6		120.6
Pacific Slope	13.8	10.0		.1		23.9
Total	4,890.2	67,552.1	1,620.5	743.2	310	73,116.0

In the last group of ores I have included Dr. Hayes's estimates of titaniferous magnetite without separate classification.

The estimates for the Eleventh International Geological Congress were grouped in a somewhat different manner, as follows:

	Available.	Probable addition.
Archean magnetites:		
Lump ores	80.0	30.0
Concentrates	40.0	10.0
Adirondack red hematites	2.0	2.0
Pennsylvania soft magnetites	40.0	....
Cambro-Ordovician brown hematites	65.0	181.0
Mesozoic and Tertiary brown hematites	10.0	15.0
Clinton red hematites	505.3	1,368.0
Alabama gray and red hematites	27.5	27.5
Carbonate ores	....	308.0
Lake Superior hematites	3,500.0	72,000.0
Mississippi Valley specular and red hematites	15.0	5.0
Mississippi Valley Palaeozoic brown hematites	30.0	45.0
Mississippi Valley Tertiary brown hematites	200.0	520.0
Cordilleran magnetites and hematites	63.8	55.0
	4,578.6	74,566.5
Titaniferous ores	90.0	128.5

As shown earlier, the annual production in recent years has totaled between 50 and 60 millions of tons. Let us assume that it will be 60 millions in the near future. Dr. Hayes's estimates indicated practically 4,800 millions of tons of available reserves or eighty years' supply. The estimates for the International Geological Congress of 1910 are not appreciably different. By just so much as the annual production exceeds the amount of 60 millions, will the time be shortened, except in so far as further exploration opens up new reserves. In mining enterprises in general, however, if the management of a company felt that it had eighty years fairly well assured, it would congratulate its stockholders on the outlook. This attitude of mind would be justified by the common experience in mining the ores of such a widely distributed metal as iron, that new reserves open up in old or new properties as old supplies are exhausted.

On the other hand, if we anticipate the general decline in the yield of ores, so that lower and lower grade reserves may be brought in; and if we assume that more tons of ore will be required to furnish the usual output of pig iron, such that the annual output of ore may reach 100 millions; then from the probable addition of reserves, given in the second column of estimates, we forecast from practically 75,000 million tons a life of 750 years. That iron could be produced in these amounts and for this period of time, there can be no doubt, if we omit consideration of cost and if we only consider possible ores down to 35 per cent. Iron-bearing rocks of still lower percentages are so abundant as to be inexhaustible. No one need feel anxiety about the physical possibility of producing iron up to the conceivable life of the race on the planet.

In earlier pages, the point was emphasized that the crux of the present situation lies in the Mesabi Range of Minnesota. Of the 55.1 million tons produced in 1912, 32.6 millions came from it. The chief point of immediate interest, therefore, is concerned with the life of the Mesabi. Its decline means great rearrangements in the present situation in the iron industry. The most recent estimates are those of C. R. Van Hise, C. K. Leith, and W. J. Mead, in cooperation, as given in Monograph 52 of the United States Geological Survey, 1911. Fifty per cent of iron in the dried ore is assumed as the minimum average yield at the time the estimates were made; 1,600 millions of tons were then credited to the Mesabi (p. 489). The output for 1910, for this range, was 30.57 millions, indicating a life of a little over 50 years. At the production of 32.6 millions for 1912, a life of almost exactly 50 years is shown. If, on the other hand, a minimum percentage of 35 in iron is considered, the same authors assign to the Mesabi Range reserves of 30,000 million tons (p. 492), which would give us 300 years of life, even at 100 million tons annual output.

The authors of Monograph 52 also discuss the reserves of the entire Lake Superior region. The reserves of 50 per cent ore, in the other ranges than the Mesabi, are less than one sixth its amount, and their combined output about two-fifths its total. Their estimated life is thus much shorter. The time period lies between 20 and 25 years. When, however, we consider a minimum yield of 35 per cent, their combined reserves are greater than those of the Mesabi, and are estimated at 37,630 millions of tons. If we credit them with two to three times their present annual output, a life of fully 1,000 years is shown.

Thus one can attack the problem from various points of view, and with varying assumptions; but the conclusion is inevitable that the output of ore from the Lake Superior region can not be kept up at the present production and with a minimum yield of 50 per cent for as much as 50 years, unless unanticipated new discoveries of rich ore are made. With diminishing yield, however, and with the tenor still at percentages above 35, the shipments of iron ore, even in increasing amounts, can be maintained for centuries.

Let us turn next to Alabama and its closely related States, Georgia and Tennessee; since, together, they constitute the second center of ore production. The great reserves lie in the Clinton ores, which are well stratified and which have been and will be explored by bore holes. The reserves are much increased by the brown ores of the region and of northwestern Alabama, and by the probable development of much older gray and red hematites in eastern Alabama; but attention will be alone directed at this point to the Clinton ores. The latter are so well stratified and persistent and are now proved

by such extensive exploration that with much confidence we may credit them, at least in the Birmingham region, with 36 to 37 per cent iron, and may consider the estimates of reserves as unusually trustworthy. Dr. C. W. Hayes, on the basis of the careful field work of C. F. Burchard,[1] estimated them at the following amounts in millions of tons.

	Available.	Not available.
Tennessee, Georgia, and northeast Alabama	88.5	440
Birmingham district, Alabama	258.5	438
Total	445.0	878

Mr. E. C. Eckel had previously credited the Birmingham district with 1,000 million tons, a number not unduly above the sum of the two figures for Birmingham given above. The officers of the Tennessee Coal & Iron Co. considered, in 1909, in round numbers 500 million tons as reliably assured.

The combined output of these three States in Clinton ore was practically 4 millions of tons in 1912, indicating at this rate 111 years' life assured, and over 200 years' additional life as probable. In these estimates we do not assume an essential falling off in the yield of the ores below percentages actively mined to-day.

Were we to take up the figures for the other portions of the country very similar results would be reached. But, as their contributions are proportionately smaller, the effects of rearrangements are less serious. Obviously, in a general way, viewing the country at large, and allowing for reasonable decline in yield, the ore supply is good for several centuries.

FOREIGN SOURCES OF SUPPLY.

The yield in the furnace is certain to be maintained, in an important manner, by importations of rich ores from abroad. These contributions are already a serious factor, since they amounted to 2.1 million tons in 1910, and had reached 2.5 millions in 1912, ranging between 3.5 and 4.6 per cent of the total.

Cuba.—The most accessible and the heaviest contributor of ore is Cuba. The mines in the vicinity of Santiago, on the southeastern coast, have been shipping for 20 years amounts which annually range below and above a half million tons of magnetite, with some hematite mechanically intergrown. The ores now run from 55 to 60 per cent in iron and are of Bessemer grade. For some years additional, these contributions will continue. The great and enduring

[1] Bulletin No. 394, U. S. Geol. Survey, pp. 88–89, 1909; No. 400, pp. 129–133, 1910.

reserves, however, are on the northeastern coast or near it. Extensive areas of serpentine have weathered in the tropical climate so as to afford a heavy mantle of alteration products, which when freed of absorbed water yield 48 per cent iron, with about 1 per cent nickel and 1 to 2 per cent chromium. When freed of additional combined water in calcining furnaces the ore reaches 56 per cent iron. The Mayari tract, already actively mined, can yield 600 million tons of excellent nickel-bearing Bessemer ore. The undeveloped Moa and San Felipe (or Cubitas) districts can swell the reserves to 2,000 million tons. Thus, as the output of the mines in the United States falls lower and lower below present percentages, more and more can the grade be kept at or near the above values by Cuban contributions to furnaces near the Atlantic seaboard. The supply of Cuban ores is sufficient to last several centuries, at any reasonable consumption of conceivable importations. They are very conveniently situated for low costs of mining and shipping.

Sweden.—In recent years, the second contributer to American furnaces has been Sweden. The supplies have come from the great magnetite body at Kiruna, in Swedish Lapland. The ore reaches the sea at Narvik in Norway, a port open all the year round, and distant from the mines 100 miles by rail. A generally high phosphorus ore is now mined, with a small proportion of rich Bessemer grade. The output is sorted into different grades, possessing from 59 to 69 per cent iron, with perhaps a general average of 65. Importations in 1912 into this country were practically 334,000 tons. The output of the mines is carefully regulated by the Swedish Government with the purpose of conserving the supply for a long life. The United States can not anticipate more than a moderate contribution from this source.

Norway.—In Norway, not far from the sea and adapted to magnetic concentration, there are additional deposits which are possibilities for the future. One enterprise is already active on the extreme northeastern frontier of Norway, east of the North Cape. The European furnaces have, however, absorbed the output hitherto.

Newfoundland.—The third source of importations, in recent years, has been Newfoundland. The shipments come from the red hematite mines on Bell Island in Conception Bay. The ores are beds of red hematite in Cambrian and Ordovician strata and are strongly reminiscent of the Clinton ores. They supply a non-Bessemer ore of 50 per cent, or slightly less, in iron, and in their best years have exported over 200,000 tons to the United States. The reserves which run beneath the sea are estimated by J. P. Howley at over 3,000 millions of tons. The ores are generally called the Wabana. With a sea voyage of 1,100 to 1,500 miles, they can reach our principal ports

of entry. Their chief markets, however, are the iron and steel centers of Nova Scotia.

Chile.—The Panama Canal has made accessible one great deposit or iron ore on the west coast of Chile, called the Tofo. Tofo is 30 miles north of Coquimbo. The ores are only three or four miles from the sea. The Bethlehem Steel Co. is making extensive preparations for shipments on a large scale in the immediate future. Published descriptions mention reserves of 100 million tons of ore ranging above and somewhat below 60 per cent and prevailingly of Bessemer grade. A possible annual output of 1.5 to 2 millions of tons is expected. (Iron Age, May 11, 1914.) Other deposits along the west coast of South America have been reported in an incomplete way, but are not yet sufficiently developed to seriously enter into our forecasts.

Brazil.—For some years past reports have been current of very large, rich, low-phosphorus deposits of specular hematite in the State of Minas Geraes, Brazil. They constitute beds in metamorphic sediments of pre-Cambrian age, and appear some three hundred and seventy-five miles from the seacoast. Deposits of hard specular hematite and loose blocks on the surface are available in enormous quantity. The first estimates, for the Eleventh International Geological Congress, by Orville A. Derby, the able State geologist of Brazil, gave 2,000 million tons. Since then the observations of Leith and Harder indicate more than three times this amount. Vast quantities run between 65 and 70 per cent in iron and are well within Bessemer limits. The chief handicap lies in the long railway haul to the sea. While railways tap the district, both from Rio Janeiro and Victoria (the latter the probable port of future shipments), the present roadbeds are not adapted to the hard wear and tear of a heavy iron ore traffic and must be rebuilt.[1] Once on shipboard, the distance to Atlantic ports is about 4,000 miles.

Europe and Africa.—The United States also import appreciable amounts of ore from Spanish, Algerian, and Grecian ports. Spain is the chief contributor, approximately 440,000 tons reaching Atlantic ports in 1910. To some extent, therefore, declining American percentages may be raised by future shipments from these sources, yet as time passes British and continental needs will be even more pressing than American and will call more insistently for supplies from European and northern African mines.

The possibilities of importation and sale turn, however, upon market conditions. Through the kindness of Mr. Charles F. Rand, president of the Spanish-American Iron Co., the following figures have

[1] The latest account is by E. C. Harder, "The Iron Industry of Brazil," Transactions of the American Institute of Mining Engineers.

been supplied the writer. They summarize market conditions and ocean freights as they have prevailed in recent years:

Ocean freight from Cuba is 95 cents a ton; from Wabana, Newfoundland, 70 cents; from Brazil, \$2.12½ (i. e., 8s. 6d.); from Sweden, \$1.50; from Spain, \$1.37½; from North Africa, \$1.25; from Chile, \$3. When the ore reaches American ports, it brings as a general rule 7 cents a unit, although specially rich and pure varieties may command 8 cents. From these data, in a general way, one can see the market conditions which must be met by an exporter of ore from any one of the countries which are the chief contributors to American furnaces. Ocean freights, for some time to come, certainly will not be less than in recent years, even when seagoing bottoms can be secured.

THE SUPPLY OF COKE.

So long as iron ore is turned into pig iron as the first step toward steel, as in our present-day practice, coke will be no less vital to the industry than ore itself. The relatively great height of a modern stack and the heavy burden of charge which rests upon the still burning fuel demand strong and resistant coke. Not every coke will answer. From an address by Mr. J. E. Johnson before the Mining and Metallurgical Society of America, January 12, 1915, the following figures are taken: From 52 per cent iron ore a ton of pig iron may be made with 1 ton of coke. These conditions are approximately those of Lake Superior ores to-day. From a 38 per cent ore, a ton of pig requires 1⅔ tons of coke, conditions approximately those of Alabama. Should we ever use 25 per cent ore, 2⅔ tons of coke will be necessary to the ton of pig. Whatever may be said, therefore, regarding the coke supply to-day will apply with increasing force as the years pass and the yield of ores declines. Anthracite coal has been, to a certain extent, used in the iron furnaces, but its desirability and increasing price for household fuel and for steam purposes in our Eastern cities make it a factor in future iron metallurgy of diminishing importance. Open-burning bituminous coal has been used raw to some extent, but is not now a serious factor.

The following table summarizes the bituminous coal reserves as calculated by M. R. Campbell, of the United States Geological Survey, and as given in the Mineral Resources of the United States for 1910, page 28. Only eastern coke-producing States are selected because the present effect of Rocky Mountain States upon the total result is not great. The influence which they can exercise upon the future is small or remote. The same is true of the Pacific coast and its possible future industry in iron and steel. In the table the

total bituminous coal reserves have been reduced by an arbitrary fraction, which is assumed to represent the portion of coking grade suitable to blast-furnace use. Much difference of opinion might arise over this reduction. Its importance turns, however, upon the ultimate result; that is, if the supply of coke proves to be a less serious matter than the supply of ore, these fractions might vary widely and yet not destroy the reliability of the final result. In the further calculations I assume that two-thirds of the coal can be ultimately mined, one-third being left in pillars. In passing from coal to coke, I use the same percentages of yield for each of the States as are given in the Mineral Resources of the United States Geological Survey for 1912, Part II, page 251. The estimates are, moreover, within the probable reserves in this additional respect that no account is taken of Illinois, although its weak coking coals, when mixed with others in by-product ovens, give suitable fuel for blast-furnace use.

Reserves of bituminous coal of coking grade in millions of long tons.

	Total bituminous.	Fraction for coking.	Two-thirds mined.	Per cent.	Coke.
Pennsylvania	109,174	¼—27,300	18,200	66.5	12,100
Ohio	85,156	1/10— 8,515	5,676	60.2	3,027
Maryland	7,802	¼— 1,950	1,300	65.8	855
Virginia	22,391	⅓— 7,464	4,976	62.2	3,095
West Virginia	149,120	¼—37,350	24,900	60.7	15,114
Eastern Kentucky	67,687	1/10— 6,768	4,512	62.4	2,815
Western Kentucky	36,104	1/10— 3,610	2,406	62.4	1,501
Tennessee	25,509	¼— 6,377	4,251	54	2,295
Georgia	920	½— 460	306	50	153
Alabama	68,594	⅓—20,865	13,910	64.9	9,027
	572,457	120,659	80,437		50,882

The production of pig iron by States in 1912—the maximum year as yet—is given in the statistics in the next table in millions of long tons. The figures are taken from the Mineral Resources for 1912 of the United States Geological Survey. If we assume that the coke consumption per ton of pig iron is one ton in those States where Lake Superior ores or others equally rich are used, one and three-quarter tons in Alabama, and one and one-half tons in West Virginia and Virginia we can make a rough estimate of the coke consumption for pig iron manufacture in a maximum year.

Pig iron production in millions of long tons, by States, 1912.

	Pig iron.	Coke consumed.
Pennsylvania	12.58	12.85
Ohio	6.80	6.80
Illinois	2.89	2.89
New York	1.94	1.04
Alabama	1.86	3.25
Indiana, Michigan	1.77	1.77
Missouri, Colorado, and California	.40	(1)
Tennessee	.34	.60
Wisconsin and Minnesota	.30	.30
West Virginia	.27	.40
Virginia	.25	.39
Maryland	.22	.22
Others	.12	.15
	29.72	31.26

[1] Omitted.

We have thus an apparent available coke supply of 50,882 million tons, and a consumption for blast-furnace purposes, in our heaviest year of production, of 31.26 millions. There are thus over sixteen hundred years' supply at this rate. In Pennsylvania, on the assumed ratio of coking coal, there is about one thousand years' supply. These time periods are so great that despite possible errors in assumptions; despite increasing coke consumption with lowering of grade of ore; and despite increasing output of pig iron, we seem justified in concluding that the fuel supply is rather more abundant than the ore supply. The reserves of bituminous coal in 1912 were placed by the volume on Mineral Resources for that year at 1,651,057 millions of short tons of which two thirds or 1,100,705 millions of short tons could be mined. With an annual production, as in 1912, of 450 million tons, a life of nearly twenty-five hundred years would be indicated. Apparently coal for general fuel will last longer than coal for coke.

THE INCREASING STOCK OF SCRAP IRON.

Much of the iron or steel, once it is used, is lost by oxidation, wear and tear, or by being thrown away. A goodly proportion is, however, returned to furnaces and worked over. For this purpose, in America, the electric furnace has proved of special advantage, as the writer learns from Prof. J. W. Richards. With growth of production and with increasing attention to the prevention of waste, now so generally manifested throughout the country, the return of old iron and steel for re-treatment is likely to ease somewhat the strain on the mines.

IMPROVEMENT IN PROCESSES.

Electrical processes of smelting, in regions of great water powers and low cost for current, have excited hopes of saving fuel. The

fuel in the blast furnace accomplishes two purposes—the production of a high temperature and the reduction of the iron oxide to the metallic state. The electric furnace could serve to replace the former portion, but carbon for the reduction of the iron oxide would always be necessary. Some heat, of course, would be developed in the reaction itself, which practically implies the combustion of the carbon. If we assume a practicable electric furnace, comparable so far as the installation is concerned with a blast furnace, we have to balance against each other the cost of heat from combustion of coke and from electric current. Thus far coke has proved more economical, although it is conceivable that countries like Sweden and Norway, with abundant water power and ores, but without coal, might develop an electric smelting industry. Charcoal would probably then furnish the reducing agent. For some time to come, we can see little chance for electric smelting in eastern North America.

Improvements are then reduced to those possible for the blast furnace itself. We are reminded of the great economies introduced by the chilling and separation of the moisture in the air to be used in the blast. A great debt is due Mr. James Gayley for this invention, which steadies the running of the furnace and keeps conditions uniform. We recall the use of the spent blast in internal-combustion engines, and the economical generation of power in this way instead of through the ordinary medium of steam. The power is then available for all manner of applications around a works, and lowers costs. We note the recent and very encouraging experimental run of some months at the Port Henry, N. Y., furnace, with large proportion of titaniferous magnetite in the charge. The reports of Mr. J. E. Bachman,[1] in charge of the furnace, do much to remove the stigma from this variety of ore and to make available large reserves now looked upon with suspicion. By just so much as these neglected ores come into use the life of the nontitaniferous varieties will be prolonged. Dr. C. W. Hayes[2] estimated the titaniferous ores in 1909 at 90 million tons available and 128.5 million tons as not at present available. Dr. J. T. Singewald[3] has concluded that in some of the areas used in the calculations of Dr. Hayes, the ores are too low for probable use. These ores have not been very generally explored as yet because of their bad reputation, but the amount is quite certainly large.

A remote possibility for improvements in the blast furnace but one worthy of careful consideration was suggested by Mr. J. E. Johnson in the address at the annual meeting of the Mining and

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[1] The Iron Age, Oct. 22, 1914, p. 938; Dec. 24, 1914, p. 1470. A complete report is in press in the publications of the Iron and Steel Institute.

[2] C. W. Hayes, Bulletin 394, U. S. Geological Survey, p. 102, 1909.

[3] J. T. Singewald, Bulletin 64, Bureau of Mines, p. 38, 1913.

Metallurgical Society of America, January 12, 1915, which has been already cited. The air passing through the furnace is, by volume, nearly four-fifths inert nitrogen, which contributes nothing to the reactions and is a serious absorber of heat. Were it possible to relatively increase the proportion of oxygen, loss of heat might be avoided and fuel consumption reduced. Mr. Johnson called attention to the production of greatly enriched proportions of oxygen by the expansion of liquid air under suitable control, as now used in practicable processes for obtaining oxygen on the one hand and nitrogen on the other. Were it possible with the low-cost power, to be developed by the products of the blast furnace, to manufacture liquid air or to produce in the same general way a strongly enriched oxygenated air for the intake, the volume of atmospheric gases would be greatly reduced and the heat economies would ensue. The contrast presented by employing the coldest substance known as a means of facilitating one of the hottest reactions of technical practice is so novel as to arrest attention. Costs, however, should it ever become practicable, place it in the remote future.

A more immediately practicable economy, involving the saving of waste, is the use of blast-furnace cinder for the manufacture of cement. By just so much as this ordinarily rejected product can be made a source of financial return, costs will be reduced. While we may not realize the whimsical ideal presented by Mr. Johnson in the above address, when he pictured the furnace of the future as yielding pig iron at the tap and cement at the cinder notch, yet we may think of slag utilization as helping to usher in the next age of the world, the one which is rapidly displacing the present steel age—the one which we all recognize as the inevitable age of cement.

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ON THE ORIGIN OF METEORITES.[1]

By Friedrich Berwerth.

In the Imperial Court Museum of National History there is preserved what is literally a heavenly treasure. Its peculiar nature is well known to the professionals of cultured nations, and to all inquiring friends of nature, while it is regarded by the great majority of people more with the vague uncertainty with which one is usually accustomed to present to strange, unusual things. I can assert with some satisfaction that, thanks to the occasional court boards of administration, to the intendants and to the former keepers of the collection, we have in this scientific treasure the largest and scientifically the most valuable collection of meteorites, and the richest in number of falls in the world. Because of this circumstance you will certainly sympathize with me if I, as the present superintendent of this precious collection, consider it my patriotic duty at your worthy and honorable invitation to explain briefly one of the most interesting chapters in the lore of meteorites.

The knowledge of stones which have fallen from heaven extends into the oldest history of humanity, back into prehistoric times. Among the Chinese the mention of heaven stones goes back to 6,000 years, and the fact of falling stones has always been recognized by the people of Asia Minor, by the Greeks and Romans, and we must not be surprised if these "messengers of heaven" were generally regarded as divine gifts. But with the advance of Christianity another opinion has become prevalent. The many meteoric divinities do not conform to its teaching and the system of the Roman established church. Gradually there was lost the oriental conception of them as blessings, and people began to regard them rather as "prodigies," or miraculous events, until through the whole Middle Ages and modern times the falling of meteorites was considered the foreboding of approaching misfortune, and the occurrence occasioned in human beings only a feeling of fear, horror, and terror.

[1] Translation from the German of a lecture given in the Scientific Club of Vienna on the 26th of January, 1914.

By the latter part of the eighteenth century the fact of the falling of stones had finally so far been forgotten that a fall which occurred near Luce in France in 1768 caused great embarrassment to the professors and academicians at Paris, because they did not know what to make of the event as related and the until then unknown material. Lavoisier, at that time a young chemist, but who afterwards became famous, stated that the meteorite might be a kind of iron pyrites.

In Vienna, also, there existed at that time a complete disbelief in meteorites. The then director of the court mineral cabinet, Andr. Xaver Stütz, expressed himself concerning the mass of pure iron of Agram, which fell in 1751, and with the acquisition of which our meteorite collection was founded, as follows:

> Certainly even the clear heads of Germany in 1751, owing to the gross ignorance prevailing at that time regarding natural history and practical physics, may have believed the dense iron masses of Agram and Eichstadt to have fallen from heaven, but in our times it would be unpardonable to consider such fairy tales even probable.

A similar conception prevailed also in America, for when someone told President Jefferson in 1807 that two professors had described the fall of a stone he declared "one can rather believe that two Yankee professors lie than believe that stones fall from heaven."

The German physicist Chladni in the year 1794 first challenged this disbelief in meteorites in his paper on the Pallas iron, and he commended meteorites to the scientific investigation which through the whole past century has been zealously kept up and furthered by certain scholars, especially here in Vienna.

Now, what do we denote as meteorites? You have doubtless all observed on clear, cloudless nights the sudden appearances and again disappearances of light and fire in the heavens. Such are known to us as comets and meteors, and meteors are again distinguished as Sternschnuppen (shooting stars, étoiles filantes), and as Feuerkugeln (fireballs or bolides). The astronomers regard these three heavenly bodies, which are not members of our solar system, as identical, one with another. They are connected by intergradational forms, and their varying appearances are but varying phases of one and the same natural phenomenon.

This identity of shooting stars and of fireballs we must, however, to-day regard as quite uncertain, since there are circumstances indicative of their independence of each other as well as of comets.

When fireballs coming from various directions in the heavens reach the neighborhood of the earth, where on dark nights they afford to human beings a sight arousing amazement through the lighting up of the landscape over which they pass as bright as day, they are seen to burst, usually with an explosion, throwing out streams of fire, accompanied by a noise comparable to the firing of musketry. Dark-

ness follows and the solid masses forming the kernel of the fireballs fall to earth in separate fragments, or as a shower of stones.

These solid masses, consisting of stone or iron, which reach our planet from space, and are transformed into balls of fire only in our atmosphere, we call meteorites. Such Weltspähne (world fragments), as Chladni once called them, have been given different names at different times according to the conception which people had of their origin or their character, as baetylus or beseelte stones, sky stones, thunderstones (ceraunites, brontoliths), thunderbolts, air stones, moonstones (uranoliths), and at present they are often called aeroliths, a name first used by Blumenbach in 1804.

Concerning the origin of these stone and iron masses opinions have greatly varied from time to time.

When Chladni's epoch-making work (The Pallas Iron, 1794) overcame the doubt as to the falling of stone and iron masses from the air, people began to seek explanations for the mysterious and still incomprehensible phenomena of the Feuerkugeln and to advance opinions as to their origin.

Passing over the beautiful, mythical conceptions of the oriental peoples, which have been already referred to, and the assumption in the middle ages that they might be due to lightning, one can generally divide into two groups those holding opinions as to the origin of meteorites—that is, into supporters of the hypothesis that they came from space and did not belong originally to the earth and its atmosphere, and the supporters of the hypothesis that they did originally belong to our planet. Each of these two main groups falls again into subgroups, first the supporters of the hypothesis that the meteorites come from unlimited space and the supporters of the hypothesis that they are ejected from lunar volcanoes. The second large group upholding the terrestrial origin of meteorites is divided into two sections, those who think that they originated from the constituents of the atmosphere and those who consider them ejected from terrestrial volcanoes.

A suggestion of Proust that meteorites may come from the poles of our earth because there the iron can not have oxidized, on account of the eternal cold, may here be mentioned only as a curiosity.

Chladni named the supporters of the four special hypotheses cosmists, lunarists, atmospherists, and tellurists. To the cosmists Chladni himself belonged first of all. He considered it possible that the meteorites might be original or chaotic material ("Urmaterie")—that is, aggregates of matter which existed in space and which had never belonged to a larger world body, but which might furnish the material from which such world bodies might be formed. Many of the nebula may be nothing else than such shining material spread through enormous spaces. Originating from these world clouds

(Weltworlken), comets and meteorites are distinguished from one another only through their relative size. The formations occurring at the boundary of our atmosphere as loose, dust-like, or gaseous aggregates lose their cosmic velocity through its resistance, and finally, by the explosions taking place, are compacted into a solid body.

Chladni, however, did not consider it impossible that the meteorites might be remnants of a destroyed world body, as an illustration of which he mentioned the disappearance of a planet between Jupiter and Mars. Olbers gave occasion for this discovery. In portraying the solar system the space between Mars and Jupiter caused him great vexation, and he anticipated that a planet might be found there. This ingenious idea was soon afterwards verified by the discovery of the asteroids Ceres, Pallas, Juno, and Vesta, which he now conceived to be broken pieces of the great planet missed by him. The little planets (asteroids), denoted here as fragments, belong to the ring now known as planetoids, * * * which a hundred years ago were reported to be angular, not always of uniform size, and therefore of irregular form and variable light intensity. We shall see further on that very recently E. Suess has claimed the vanished planet and the planetoids which were derived from it as the sources of our meteorites.

There were many respected adherents of the hypothesis of the origin of meteorites from the volcanoes of the moon. Telescopic observation had at this time already given information as to the surface of the moon, "upon which there were overlapping mountains, large chains of mountains extending for great distances, depressions, craters, and planes," so v. Ende writes in his book "Ueber Massen und Steine die aus dem Monde auf die Erde herabgefallen sind," 1904. V. Ende endeavors to strengthen Chladni's hypothesis and to establish, or at least make probable, the connection between the earth and its satellites. Olbers first expressed the moonstone hypothesis on the occasion of the fall of a meteorite at Siena in 1795.

The great geometrician Laplace expressed the same supposition, which Blumenbach also took up with much approval and called it "the most plausible opinion concerning these things." Arago and Smith were also of the same opinion, and Berzelius, too, was an active follower of the lunar hypothesis in 1836. According to his opinion the meteoric stones came from two different volcanoes on the moon. * * * But when it was established that a volcano on the moon would not possess sufficient energy to impart to an ejected block of stone the necessary initial velocity to reach our earth the hypothesis of the lunar origin fell into disfavor. Strange to relate, it has, however, even at the present day, some individual upholders—for example, the Dutchman Verbeeck, who considers that the glasses

(tektites) which are conceived by Franz Suess to be meteorites are glass meteorites from the moon.

For the sake of justice I must also mention that the lunar hypothesis had a predecessor in the writer Paolo Maria Terzago, who, in the description (1660) of the fall of a stone at Milan in 1650, at which a Franciscan monk was killed, expressed the opinion that the "moon was the cause of the falling of the stones."

The idea, according to which meteorites were formed out of constituents of the atmosphere, was held only so long as their composition was yet little known. It was soon seen that iron, nickel, chromium, silica, etc., could not be contained in the air, and Klaproth noted also that iron would necessarily be oxidized under these conditions. Many other reasons, such as the occurrence of the fireballs at a great height, their velocity, and occurrence at all times of the day and year, among other things, early withdrew every support from the hypothesis of the origin of meteoric masses in the atmosphere.

Of longer duration was the theory of their terrestrial origin—that is, that they had a connection with the formation of the earth—even though not the ejecta of volcanoes (with which, indeed, they do not entirely coincide). A terrestrial derivation in this sense was ascribed to meteorites by Lagrange and later by Tisseraud. According to this they are said to have been thrown out of the interior of our planet in the dim early ages with so great force that they were carried beyond the limit of its attraction to form a ring about it, like that of Saturn, out of which fragments fall to the earth again. Such a conception with somewhat different foundation we shall find later held by V. Goldschmidt.

Little reference is made to meteorites by astronomers at the beginning of the last century. The books on astronomy of those times contain nothing at all about fireballs. Even Bode in his "Introduction to the Knowledge of the Starry Heavens" (1823) devotes only the following lines to our subject:

> The so-called flying dragon, the leaping goat (capra saltans), torches, burning beams, and other shining meteors probably have the same nature and consistency in part as the falling stones, and are only distinguished from them in size and shape. Partly they may also consist of thick and viscous vapors of the lower air, which give off a phosphorescent light through a decomposition of their original materials and are blown away by the wind in all sorts of chance forms and shapes.

Astronomic hypotheses as to the origin of meteorites did not develop until a much later time, and took their rise from the idea that meteorites, shooting stars, and comets were all of the same character. Schiaparelli in 1871 suggested important reasons for the connection between the three kinds of phenomena, reasons which were also

presented with a few changes by the Viennese astronomer Weiss. It was thought that they could assume with some certainty that the shooting stars are bodies as solid as are the meteorites which penetrate with cosmic velocity the atmosphere of the earth, where they become glowing in the heated air and begin to shine, and after being resolved to dust or consumed become extinct or pass out of the atmosphere.

After it had been shown that swarms of shooting stars have been returning regularly for two and one-half thousand years and proceed from a definite point of radiation in the sky, then it was considered the only possibility that the swarms of meteors circling around the sun intercept the orbit of the earth at some point, on the approach to which, in consequence of the density of the earth, a portion of them fall down upon our planet as little meteoric bodies. From the period of rotation, direction, and other factors we have learned how to calculate the course of the meteors and have found that their orbits very nearly coincided with those of the periodic comets. Thus the Leonids move in the orbits of the comet Tempel, 1866, the Perseids in that of the comet 1862 III, and the Bielids of the 27th to 29th of November in the course of the comet Biela. The agreement is so consistently exact that a whole series of meteor streams can with great probability be traced back to orbits of known comets. That comets are divided by the influence of the sun or of the planets, as has happened to the comet Biela, or altogether break to pieces and scatter themselves along the course of the comets and form a meteoric ring out of which come the swarms or shooting stars; all these coordinate occurrences tend very convincingly to identify the falling meteorites with the shooting stars, and to the belief, therefore, that they are broken pieces of comets. A difference between shooting stars and meteorites consists, then, only in that the first named pass noiselessly across the heavens and disappear, while the fireballs hurl their missiles, the meteorites, with thundering noise upon the earth. This theory is still held in esteem among astronomers, and is also taken up by Trabert in his Textbook of Cosmic Physics, 1912. The hypothesis can be quite briefly expressed in the following words: Comets which have become periodic split up into periodic swarms of shooting stars which revolve in the courses of the mother comet. The fireballs are, then, nothing more nor less than shooting stars which have been driven into lower layers of air and appear to us in larger sizes.

According to all these conceptions one would expect that at times of the abundance of shooting stars, especially of the Leonid and Perseid swarms, there would occur an increase of meteorite falls. Among the about 350 known falls some, to be sure, have fallen at

these times. Thus the iron of Mazapil is said to have come from the meteoric shower of the 27th of November, 1885, and, according to this, is a fragment of the comet Biela. But this must remain a mere assumption. The time-table of meteorite falls gives proof that the great majority of meteorites have not come to the surface of the earth at the time of swarms of shooting stars.

In opposition to this briefly outlined theory, according to which the meteorites represent a part of the shooting-star phenomena, an hypothesis was proposed in the seventies in the past century which did not take its origin from astronomical assumptions. It was based on a mineralo-geological basis, upon the study of the component material of the meteorites, and upon the times of arrival of meteorites of like composition. This new (volcanic) hypothesis, founded upon actual observations, was presented in 1875 by G. Tschermak, of the Viennese Academy of Sciences, and was later through supplemental work augmented and established. If Brewster, L. Smith, Haidinger, and Daubree have claimed the origin of meteorites through the dissolution of a heavenly body, so the disintegration of small celestial bodies is for the first time ascribed by Tschermak to a volcanic process. From the shape of meteorites it is to be concluded that they are actual ruins or broken bits which may come from larger planetary masses. Not only their shapes, but also the slicken-sided surfaces occurring in meteorites point to fracturing in the mass, and many are like volcanic tuffs or clastic masses, as Haidinger and Reichenbach have already suggested. Where Daubree leaves it undecided whether the fragmentation of a world body is brought about by collision or by explosion, Tschermak based his decision that they resulted from explosive destruction on the physical condition of the meteorites, which are formed by volcanic explosions unaccompanied by the pouring out of lava just as terrestrial stones which come from explosive craters (similar to the Maaren of Eifel). An explosive activity to which meteorites point can only be brought about by sudden expansions of gases and steam, among which hydrogen may have been in the first rank. Vulcanism as a cosmic phenomena is the destroyer of planetary masses, as we learn from the constituents of meteorites, in harmony with the solar development of stars, which all go through a volcanic phase. The broken bits after their separation are arranged in swarms which cross the orbit of the earth in accordance with law. The most convincing examples for the existence of meteorite streams are formed by the group of eukrites.

If one ascertains their orbits and the intersection which they make with that of the earth, one finds that this intersection is progressively retarded, which means that the line of nodes relative to the earth

retrogrades. From the calculation of the time of the nodes of intersection and comparison with observations Tschermak was able years ago to predict the next falling of a eukrite for about the end of October, which calculation was actually borne out by the falling of the eukrite of Peramiho on the 20th of October, 1899.

For the four undoubtedly similar eukrites of Stannern, Jonzac, Juvinas, and Peramiho, the retardation of the intersection was found proportional to the time by the formula (E=longitude of node) $E=230.64+1.6175t$, in which t denotes the number of the year minus 1800.

The greatest difference between the observations and the calculation is not more than one and one-half days. From the determined return and the regular shifting of the lines of nodes, which yearly corresponds to a change of 1° 36′, there is therefore very great probability for the astronomic connection of the eukrites.

Although v. Niessl did not find the astronomic courses of these eukrites to be identical, which means that they did not indicate the same point of origin, still one can always consider as open the possibility that the Stannern, Jonzac, and Juvinas stones came from the same region in space, when one considers that the testimony of eye-witnesses as to the course of fireballs is subject to great error because of the suddenness of the occurrence.

According to v. Niessl[1] the meteorite falls move in hyperbolic courses, which, however, does not shut out the possibility that meteorites occur which move in elliptical courses like planets. Firm support also for this meteoric hypothesis, deduced from indisputable facts, comes from astronomic consideration. More recent observations have shown that there is a difference in kind between the material of meteorites and shooting-stars. If one arranges the meteorites according to their specific weight, a series results, which begins with the carbonaceous forms, of the density 1.7 to 2.9. Then follow those bearing feldspar with the density 3 to 3.4, those containing bronzite and olivine (mostly chondrites) with the density 4 to 7, and finally the irons of the density 7.5 to 7.8.

Carbonaceous meteorites	1.7–2.9
Feldspar-bearing meteorites	3.0–3.4
Bronzite-olivine-bearing stones (mostly chondrites)	4.0–7.0
Iron	7.5–7.8

In the face of the lesser densities, which are found in the moon (3.4) in comparison with the earth (5.6), and which decrease in the

[1] Determination of Meteor Orbits; Smithsonian Miscellaneous Collections, Vol. 66, No. 16, 1917.—TRANSLATOR.

outer planets of the solar system to 1.4 in the planet Jupiter and 1.1 even in Neptune—

	Density.
Earth	5.6
Moon	3.4
Jupiter	1.4
Neptune	1.1

the supposition becomes the greatest probability that in space particles are spread abroad in clouds of loose consistency, which consist of matter like rock dust, salt-like compounds, carbon, and hydrocarbons, which come into the solar system in streams and upon their entrance are consumed, leaving behind carbonic acid, vapor, and fine dust.

The Tschermak hypothesis mentioned here gains in importance when we consider the opinions of many astronomers of to-day, according to which the completion of the heavenly bodies is inconceivable without vulcanism. One need but observe the conditions upon our earth, the moon, and the sun. Also, we find on the comets with elliptic courses phenomena which may be connected or compared with volcanic occurrences. Hertz considers the comet tails to be electric waves, Goldstein considers them kathode tufts, others consider them alpha rays of helium, and Svante Arrhenius declares them of mechanical origin, formed through pressure of light radiation. He considers the particles of the comets so tiny that they no longer obey the law of gravitation, but are forced out into space by the light rays of the sun, and by electric discharges in the heads of the comets, which also work repulsively upon the material forming the tail. All these phenomena are straightway compared with the great stresses in the interior of the planets, as with volcanic forces, which also Tschermak has applied to the explosive fragmentation of small world bodies and by this means has explained the origin of meteorites.

Paying due respect to the opinion of Daubree on the relationship of meteorites to planets and to Tschermak's derivation of meteorites from small planetary bodies, E. Suess reminds us of the variability in the light of the planetoids as observed by Seeliger and Wolf. Since the course of the latter lies partly outside and partly inside that of Mars, his view is corroborated that between Mars and Jupiter there has existed a unified planetary mass which, according to our knowledge of the constituents of meteorites, must have come from the basic rocks occurring in the kernel of the earth. We therefore find here Tschermak's conception applied to the dissolution of a definite planet which Olbers missed 100 years ago and in the place of which the planetoids were discovered. Suess says: "Meteorites and planetoids are nothing else than the passing witnesses of an episode which has taken place in the history of our planetary system."

The lively interest in the visitors to our solar realm which have come to us has aroused numerous other investigators to take a stand as to the origin of meteorites. Goldschmidt applies his "Komplikation law," which he has been able to prove in crystalline forms and musical harmony—also to harmony in space—and relegates the formation of meteorites to the time of the separation of the moon from the earth's sphere, at which time neither moon nor earth absorbed all the disrupted material, the residuals being condensed into drops which now probably run their course as meteorites around the earth and are called cosmolites.

Svante Arrhenius, in a very recent work, puts the origin of meteorites into the realm of nebula or nebulous stars beyond our solar system. He considers that the little particles separated out by the suns through ray pressure meet in space and collect into aggregates of cosmic dust or meteor stones. The stony aggregates not falling upon the other worlds form a kind of haze, which is the reason that the largest part of the sky between the stars is dark.

If we recall the differences mentioned by Tschermak between shooting stars and meteorites, then the results of the investigation of the American astronomer, W. J. Pickering, give strength to the hypothesis of Tschermak, since he has found that the courses of the shooting stars and meteorites have different fall curves and the meteorites form a girdle like the asteroids. He recognizes in the stony meteorites similar orbits to those of the planets. On the other hand, they are conceived by Goldschmidt as products of separation at the time of the formation of the moon, while the meteoric irons, moving with a greater velocity, are relegated to the comets.

If we pass in review the changing opinions of the century regarding the origin of meteorites, we shall without hesitation grant to them the right of membership in our solar system. We shall consider their stellar origin and their coming in from strange worlds as improbable, and shall marvel at them according to their constitution and their forms as broken bits of a world body destroyed by volcanic events.

THE PRESENT STATE OF THE PROBLEM OF EVOLUTION.[1]

By Prof. M. CAULLERY.

The exchange of professors between the Sorbonne and Harvard University for the first time brings to Cambridge a professor of science. In a certain way I come in return for the visits which Prof. M. Bôcher and Prof. W. M. Davis have already made to the faculty of sciences at Paris. All my predecessors belonged to our faculty of letters. All have brought back a recollection of the hearty welcome which they received, and what they told me contributed largely in inducing me to accept the mission which was offered to me. I had the assurance of good will and generous sympathy from my colleagues as well as from my pupils.

In the beginning I must excuse myself for not being able to express myself, at least for the present, in English. The most important point in teaching is clearness in expressing thoughts. By speaking to you in my own language I hope to succeed much better in a difficult subject, and for that reason to obtain forgivness for the effort which, to my regret, I occasion you.

The purpose of the exchange between the two universities is to convey to the one the methods of teaching employed in the other. I have the honor to occupy at the University of Paris a chair of biology especially devoted to the study of the evolution of organic beings. It is then to the present state of this great problem that the lectures which I am going to give will be dedicated. I do not enter upon this subject here without some apprehension. Certain of my predecessors by the very nature of their subjects were able to have, at least, the illusion that Europe is still the veritable center of learning. But I have not this advantage. The necessary conditions for the development of the sciences are now at least as well fulfilled—I will even say better fulfilled—in the United States than in Europe, and for many of the sciences Europeans coming to this country have as much to learn as to teach. This seems to me particularly the case

[1] An introductory lecture in a course offered by Prof. M. Caullery as exchange professor at Harvard University, Feb. 24, 1916. Translated from the French by Mrs. C. H. Grandgent. Reprinted from Science, April 21, 1916.

in biology and especially in the questions connected with the problem of evolution.

Besides, the advance of American science in these directions does not date from yesterday. In the study of paleontology, which has a large place in the questions with which we are to concern ourselves, your scholars have, for a long time, been working with activity and considerable success the marvellous layers of American deposits, and have drawn from them, to cite only one instance, magnificent collections of reptiles and mammals, which we come to admire in the museums on this side of the Atlantic. Here more than anywhere else have been enlarged the paths opened a century ago by George Cuvier. In zoology, properly speaking, the museum of comparative zoology, in which I have the honor to speak at this time, justly famous in Europe, bears witness to the importance and long standing of the results accomplished. Louis Agassiz, more than half a century ago, was one of the most eminent names of his generation. Later, when the investigation of the great depths of the ocean marked an important and consequent stage in the knowledge of earth and life, Alexander Agassiz, his son and illustrious successor, was one of the most eager and skillful workers. The expeditions of the *Blake* and of the *Albatross* are among those which have drawn from the deep the most important and most precious materials, and their results have been the most thoroughly studied. The personality of Alexander Agassiz, whom I had the honor of meeting in Paris about 13 years ago, made upon me a striking impression. His real laboratory was the ocean, and he succeeded to the end of his life in maintaining an activity that corresponded to its amplitude. He was truly the naturalist of one of the great sides of nature. Around Louis and Alexander Agassiz, the museum and the laboratory of comparative zoology of Harvard College have been for a long time a center of studies of the first rank. In the domain of embryology Charles S. Minot also has carried on important work. But it is especially at the present moment that American biological science has made an amazing advance which expresses itself in the excellence of publications and in the results which they reveal by the number of collaborators, the activity of societies, the number of laboratories, and the abundance of material resources at their disposal. Here occurs a special factor, which has considerable importance, the enlightened and large generosity of numerous patrons. It is incontestable that men of talent find more easily in America than in Europe, and especially at the age of their full activity, the cooperation without which their greatest efforts are to a certain extent barren. Now, at the point to which we have arrived, the greater part of scientific problems demands the exercise of considerable pecuniary resources and of collaborators of various ca-

pabilities. This is particularly true of biology, where, moreover, many questions, notwithstanding their scientific importance, do not lead to practical application, at any rate immediately. We succeed too rarely in Europe in combining these resources, above all in combining them rapidly enough. The European public does not sufficiently realize their necessity and interest. And the action of the state necessarily lacks the flexibility needful for rapid realization. Thus Pasteur was able to organize the institution which bears his name only at the end of his life, and at the inauguration he was heard to say mournfully, "I enter here defeated by Time." In America the power and the eagerness which private initiative gives provide for this need. Truly the greatest wonder is that this liberality is generally well conceived and well employed.

It is also true that the problems of the day in contemporaneous biology are nowhere else attacked at the present time with such activity, perseverance, and success as in the United States. As we look at different points on the biological horizon we see the studies on the Mendelian theory of heredity in full development in numbers of laboratories. It will be enough for me to cite in this connection the names of Messrs. Castle and East in this very spot, and that of Mr. T. H. Morgan, in New York. In the realm of the physiology and the structure of the cell and of the egg, the researches of E. B. Wilson, and of his pupils on the chromosomes; of J. Loeb on experimental parthenogenesis; of F. R. Lillie on the fertilization of the egg; of Calkins, and recently of Woodruff, on the senescence of the infusoria, suffice to show the share which this country has had in the advance of knowledge. And I ought also to mention numerous works on embryology and on the study of the filiation of the cells of the embryo (cell lineage), on regeneration, on the behavior of the lower organisms, on geographic distribution, and the variations of the species studied from the most diverse sides; all branches of biology are flourishing vigorously. In addition, the United States, more than any other country, has developed scientific institutions designed for the study of the application of biology to agriculture, to fisheries, etc.

In the face of this situation, I wish to make it clear at the outset that I have not the least expectation of bringing here a solution of the problem of evolution. I have too full a realization of the extent of the scientific movement aroused by this question in the United States, and I hope to derive great benefit myself from my stay here, from the contact which is permitted me with my colleagues and with their laboratories. This latter advantage is not the least which arises from the exchange between the two universities. Nor have I the expectation of bringing to you a new

solution of the problem, nor of examining it from a special and original point of view, such as might be the case in a single lecture or a small number of lectures.

I will adhere strictly to the point of view of the instructor, taking the question as a whole, expounding it in its older aspects as well as in its more recent ones. The interest in these lectures is, above all, in my opinion, in the coordination of facts and in their critical examination. As this coordination is influenced in a large measure by the surrounding conditions, the view that a naturalist has of them in Paris ought to be interesting here. In questions as complicated and as undeveloped as these still are, where we have not reached a precise conclusion, the relations of facts can not be established in a harsh and unequivocal fashion. This is particularly true of the problem of evolution at the point we have reached. During the last few years very rapid and great progress has been made in our knowledge relative to certain kinds of data, notably heredity and variation. But they have not failed to shake markedly the notions which previously seemed to be at the very foundation of evolution. One of my compatriots, an ardent disciple of Lamarck, F. Le Dantec, wrote even as far back as eight years ago a book bearing the significant title "La Crise du Transformisme,"[1] in which he brought out the contradictions in question, contradictions which, according to him, were to result in the ruin of the very idea of transformism. Since that time opposition has become even more marked, and at the present day, either tacitly or explicitly, certain of the most authoritative men, by their works, have arrived very near to a conception which would be the negation of transformism rather than its affirmation.

The term "evolution," in French, at least, has had historically two contrary meanings. In the eighteenth century it was the expression of the theory of the preformation or "emboitement" of the germs, according to which the lot of every organism was determined from the beginning. The succession of generations was only the unfolding (evolutio) of parts that existed from the beginning. In the nineteenth century, and it is in this sense that it is always used now, it had an opposite sense; it is the synonym of transformism and it signifies the *successive* transformation of animal or vegetable organic types, not realized beforehand, in the course of the history of the earth, under the influence of external causes. Now, if one admits the general value of certain of the ideas recently expressed, evolution would be only the unfolding of a series of phases completely determined in the germs of primitive organisms. It is a reversion, under a modern form, to the idea which the word evolution

[1] Nouvelle collection scientifique," Paris, Alcan.

represented in the eighteenth century. It is unnecessary to say that I use the word evolution in its nineteenth-century sense, which is synonymous with transformism. It is evident then that all is far from being clear in the present conception of transformism and that, in consequence, an exposition of its various aspects and an effort to coordinate them is not a useless thing in a course of lectures. Furthermore a comprehensive glance at the principal questions which we shall have to examine will make my meaning clear and will give me the chance to indicate the general plan of the course.

In spite of the contradictions to which I have just alluded, the reality of transformism as an accomplished fact is no longer seriously questioned. We can make the statement that, in the unanimous opinion of biologists, evolution—that is to say, the gradual differentiation of organisms from common ancestral forms—is the only rational and scientific explanation of the diversity of fossil and living beings. All the known facts come easily under this hypothesis. All morphology in its different aspects, comparative anatomy, embryology, paleontology, verifies it. By virtue of this same hypothesis these different branches of morphology have made an enormous progress since Darwin's day. The significance of certain categories of facts, especially in the domain of embryology, may have been exaggerated. Scientific men have certainly overworked the idea that the development of the individual, or ontogeny, was an abridged repetition of phylogeny—that is to say, of the several states through which the species had passed—an idea which Haeckel raised to the fundamental law of biogenesis and which a whole generation of naturalists accepted almost as a dogma. Without doubt ontogeny, in certain cases shows incontestable traces of previous states, and for that reason embryology furnishes us with palpable proofs of evolution and with valuable information concerning the affinities of groups. But there can no longer be any question of systematically regarding individual development as a repetition of the history of the stock. This conclusion results from the very progress made under the inspiration received from this imaginary law, the law of biogenesis.

The first part of the course will be devoted then to the consideration of the general data which morphology furnishes toward the support of the idea of evolution. Thus we shall see what conception comparative anatomy, embryology, and paleontology afford us of the way in which evolution is brought about, and within what limits we may hope to reconstruct it. Evolution is essentially a process which belongs to the past and even to a past extraordinarily distant. It is a reasonable supposition that evolution is going on to-day, but let us remember that nothing authorizes us to believe that what we may observe in the present epoch about

organisms will necessarily explain the succession of their former states. Evolution is an irreversible process and one which has not progressed at a uniform rate. We must not, then, expect to verify necessarily by the present organisms all the facts disclosed by morphology. It follows in my opinion that morphological data may force upon us indirectly certain conclusions even though we should have no experimental proof of them in contemporary nature.

Because of this very limitation which I have just pointed out, much of the difficulty of the study of the mechanism of evolution arises and to this may be attributed many of the profound differences among naturalists on the subject of evolutionary mechanism. The second part of the course will be devoted to the examination and the criticism of the solutions that have been proposed.

In a general way, the study of the mechanism of evolution is that of the reciprocal influence of agents external to the organisms, on the one hand, and of the living substance, properly speaking, on the other hand. There are, then, if you wish, the external factors which together constitute the environment, and the internal factors which are the specific properties of the organism. These two elements are very unequally accessible to us. The environment is susceptible of being analyzed with precision, at least as far as the present is concerned, and we can surmise it with enough probability as to preceding periods. We know very much less about living matter, and especially about the way in which its properties may have varied in the course of time. Hence one meets with two tendencies which have been encountered ever since the evolutionary question arose and which are still very definite and very contradictory in their effects on the general theories of evolution. One of those attributes a large share to the external factors and attempts to explain facts by physicochemical actions which are directly accessible. The other sees in internal factors, in the intrinsic properties of the organism itself, preponderant if not exclusive agents.

The first tendency attracts us more because it gives a larger share to analysis; that is to say, to the truly scientific method. The second flatters our ignorance with fallacious verbal explanations. It is open to the objections brought against vitalist conceptions; and when, as is the case of certain old and new theories, we come to restrict the effective rôle to internal factors alone, we may ask ourselves whether there is a really essential difference between conceptions of this nature and creationist ideas; between declaring that species have been created successively and arbitrarily by an arbitrary sovereign will, without the external world having influenced their structure, or maintaining that organic forms succeed one another, derived, to be sure, one from another but following a succession that is really determined in advance and independent of

external contingencies. Between such views there is in reality no considerable difference. Such an idea substitutes for successive creations one initial creation with successive and continuing manifestations. The present crisis of transformism, as Le Dantec and others set it forth, is the conflict concerning the reciprocal value of external and internal factors in evolution.

The two principal and classic solutions proposed to explain evolution were based on the efficacy of external factors, both the theory advanced by Lamarck in 1809 in his Philosophie Zoologique, as well as that of Darwin, formulated in 1859, in The Origin of Species. Lamarck starts in fact with the statement that the structure of organisms is in harmony with the conditions under which they live and that it is adapted to these conditions. This adaptation is, in his opinion, not an a priori fact, but a result. The organism is shaped by the environment; usage develops the organs in the individual; without usage they become atrophied. The modifications thus acquired are transmitted to posterity. Adaptation of individuals, inheritance of acquired characteristics—these are the fundamental principles of Lamarckism. Except for its verification, it is the most complete scientific theory of transformism which has been formulated, because it looks to the very cause of the change of organisms by its method of explaining adaptation. Darwin adopted the idea of Lamarck and admitted theoretically adaptation and the inheritance of acquired characteristics, but he accorded to them only a secondary importance in the accomplishment of evolution. The basis for him is the variability of organisms, a general characteristic whose mechanism he did not try to determine and which he accepts as a fact. This being so, the essential factor of the gradual transformation of species is the struggle for life between the individuals within each species and between the different species. The individuals which present advantageous variations under the conditions in which they live have more chance to survive and to reproduce themselves; those which, on the contrary, offer disadvantageous variations run more chance of being suppressed without reproducing themselves. There is established, then, automatically a choice between individuals, or, according to the accepted terminology, a *natural selection*, a choice which perpetuates the advantageous variations and eliminates the others. And with this going on in each generation the type is transformed little by little. Natural selection accumulates the results of variation.

This is not the time to discuss Darwin's theory. I wish only to observe at this time that it is less complete than that of Lamarck in that it does not try to discover the cause of variations; also that, like that of Lamarck, it attributes a considerable participation to the con-

ditions outside the organism, since it is these finally which decide the fate of the variations. And one of the forms in which the opposition to the transformist ideas, at the time of Darwin, manifested itself was the very argument that if organisms had varied it was only because of an internal principle, as Kölliker and Nägeli have more particularly explained.

The biologists at the end of the nineteenth century were divided with regard to the mechanism of evolution into two principal groups, following either Lamarck or Darwin. Among the neo-Lamarckians some have accorded to natural selection the value of a secondary factor, holding that the primary factors are the direct modifying influences of the surroundings which according to them cause the variations. Selection came in only secondarily, by sorting out these variations and especially by eliminating some of them. Such was the particular doctrine developed by my master, A. Giard, at the Sorbonne. Others have more or less absolutely refused to grant any value to selection. Such was the case of the philosopher Herbert Spencer. We must also recognize that, since the time of Darwin, natural selection has remained a purely speculative idea and that no one has been able to show its efficacy in concrete indisputable examples.

The neo-Darwinists, on their side, have in a general way gone further than Darwin because they see in selection the exclusive factor of evolution and deny all value to Lamarckian factors. This was the doctrine of Wallace, and has been especially that of Weismann. I will digress a moment to speak of the ideas of these last-mentioned authors, because of the influence which they have exerted and still exert, correctly in some respects, incorrectly in others, at least as I think.

Weismann attacked the doctrine of the inheritance of acquired characteristics and has incontestably shown the weakness of the facts which had been cited before his time in support of this kind of heredity. But he went too far when he tried to show the impossibility of this form of heredity. In so doing, he starts from a conception which meets with great favor—the radical distinction between the cells of the body proper, or *soma*, and of the reproductive elements, or germ cells. He saw in these two categories distinct and independent entities, the one opposed to the other. *Soma*, which constitutes the individual, properly speaking, is only the temporary and perishable envelope of the *germ*, which is itself a cellular autonomous immortal line, which is continuous through successive generations and forms the substratum of hereditary properties. The germ alone has some kind of absolute value. The *soma* is only an epiphenomenon, to use the language of philosophers. The *soma* is, of

course, modified by external conditions, but for one to speak of the inheritance of acquired characteristics, the local modifications of the *soma* would have to be registered in the germ and reproduced in the same form in the *soma* of following generations in the absence of the external cause which produced them in the first place. Now, says Weismann, the possibility of such an inscription, as it were, upon the germ of a modification undergone by the *soma* is not evident a priori, and when we go over the facts we find none supporting this conclusion. There are, indeed, modifications which appear in one generation and which are reproduced in the following generations; but Weismann goes on to attempt to prove that at their first appearance they were not the effect of external factors on the *soma*, but that they proceeded from the very constitution of the germ; that they were not really acquired and somatic, but were truly innate or germinal.

Such, reduced to its essential points, is the negative contention of the doctrine of Weismann. It rests upon the *absolute* and abstract distinction between the *soma* and the *germ*. In spite of the support which this conception has had and still has, I consider it, for my part, as unjustifiable in the degree of strictness which Weismann has attributed to it. It is true that the advance in embryology and cytology often allows us to identify the reproductive tissue and to follow it almost continuously through successive generations, but the conception of its autonomy is at least a physiological paradox. Though the continuity of the germ cells is sufficiently evident in many organisms, it is more than doubtful in others, particularly in all those which reproduce asexually; that is to say, many large groups of animals like the Cœlenterata, the Bryozoa, the Tunicata, and many plants. This has more than the force of an exception; it is a general principle of the life of species. One can not, then, say that the conception of Weismann carries full conviction. But this conception exercised a tyrannical influence upon the minds of contemporaneous biologists, and it is exclusively through it that most of them look at the facts.

Weismann, besides, exercised a considerable influence by championing a theory of heredity based at the start on the preceding ideas. This theory, built with undoubted ingenuity and adapted to the knowledge gained from the study of cell division, turns out on the other hand to agree with the recent works on heredity.

Lamarckism and Darwinism shared the support of biologists up to the end of the nineteenth century, discussion being in general restricted to speculation. The controversy begun in 1891 between Weismann and Spencer, who represented the two extremes, gives an idea of the extent to which one could go in this direction.

The last 20 years constitute indisputably a new period in the history of transformism where the field of discussion has been renewed, and scientists have sought to give it a much more positive and experimental character. Two kinds of investigation have been developed in this direction: On one hand the methodical study of variations, and on the other that of heredity and especially of hybridization. These two categories overlap.

Note that this new point of view is not, properly speaking, a study of evolution. According to it, variation and heredity in themselves, under present conditions, are analyzed independently of all hypothetical previous states of the organism. Afterwards the results obtained with the Lamarckian, Darwinian, and other succeeding theories will be confronted.

The sum of these researches, which are now in high favor, is a new and important branch of biology, which has received the name of *genetics*. It defines for us in particular the hitherto very vague notion of heredity and seems certain to lead us to an analysis of the properties of living substance somewhat comparable to that which the atomic theory has afforded concerning organic chemistry. We can not maintain too strongly its great importance. As far as the theory of evolution is concerned, the results obtained up to this time have been rather disappointing. Taken together the newly discovered facts have had a more or less destructive trend. In truth the results obtained do not agree with any of the general conceptions previously advanced and do not show us how evolution may have come about. They have a much greater tendency, if we look only to them, to suggest the idea of the absolute steadfastness of the species. We must evidently accept these facts such as they are. But what is their significance? On the one hand they are still limited, on the other hand, as I have already stated above, and as I shall try to show in the following lectures, the advances made by the study of heredity in organisms at the present time and under the conditions in which we are placed, does not permit us to accept ipso facto the doctrines of heredity for all past time and under all circumstances.

To use a comparison which has only the force of a metaphor but which will make my thought clear, the biologist who studies heredity is very much like a mathematician who is studying a very complex function with the aid of partial differential equations and who tries to analyze the properties and the function about a point without being able as in the case of an elementary function to study it in itself, directly, in all its aspects. The properties ascertained about one point are not necessarily applicable to all space.

As far as the organisms are concerned, the conditions of their variability have not certainly been the same in all periods. The

idea of a progressive diminution of their variability has been often expressed, notably by D. Rosa. Le Dantec, according to his favorite theoretical method in which he considers only the fundamental principles of the problem, has tried to reconcile these facts with the Lamarckian doctrine in his book on La Stabilité de la Vie.[1] In the transformation of organisms as well as in that of inert matter, he regards every change as the passage from a less stable to a more stable state. The many organisms, after having varied much and rapidly, might then, perhaps, be for the present in a state of very constant stability, at least the greater part of them. But for the time being I must omit further consideration of this suggestion.

We shall have then in the third part of the course to examine, while bearing in mind the preceding opinions, the general results of recent researches in variation and heredity. I shall now sum up the principal lines of investigation preparatory to tracing the plan of these lectures.

The methodical study of variations in animals and in plants has led us to recognize that the greater part of these variations are not inherited. If we apply to them the methods of the Belgian statistician Quetelet, we shall perceive that for each property numerically stated the different individuals of a species range themselves according to the curve of the probability of error, the greatest number of individuals corresponding to a certain measure which represents what is called the mean. The term *fluctuation* is given to those variations that are on either side of the mean and the study of these fluctuations, begun in England by Galton, has been developed and systematized by H. De Vries and Johannsen.

In short, it is the whole of the curve of fluctuations which is characteristic of heredity in a given organism, and not such and such a particular measure corresponding to a point in the curve. In cross-bred organisms there is, in each generation, an intermixture of two very complex inheritances, since these organisms result from an infinite number of these intermixtures in former generations. On the contrary, the problem is very simplified, if one considers the organisms regularly reproducing themselves by self-fertilization as is the case in certain plants. Here there is no longer in each generation a combination of new lines, but a continuation of one and the same line. It is the same hereditary substance which perpetuates itself. The Danish physiologist and botanist Johannsen attacked, as you know, the problem in this way, by studying variation along a series of generations in lines of beans, and the conclusion of his researches, which have had in recent years a very great influence, is *that each pure line gives a curve of special fluctuations under special*

[1] "Bibliothèque scientifique internationale," Paris, Alcan.

conditions. The variations that we observe in the action of external agents explain the different reactions of the hereditary substance to the conditions of the environment, but this substance itself remains unaltered. The consequence is that, in what since the time of Linné we have considered a species, and have admitted to be a more or less real entity, there is an infinity of lines, more or less different among themselves in their hereditary properties, which are fixed and independent of environment. This it is that Johannsen calls the *biotype*, or *genotype;* a species is nothing but the sum of an infinity of genotypes differing very little from one another. H. De Vries on his side reached analogous views which prove to harmonize with the results and ideas formulated some 40 years ago by a French botanist, Jordan, an unyielding adversary of transformism. Jordan, too, by means of well-ordered cultures, had analyzed a species of crucifer (*Draba verna*) in 200 elementary species independent of one another. He deserves to be considered in any case as the precursor of the ideas of which I have just given a synopsis.

It is not, then, in ordinary varibility, as it was known up to this time, that one can, following the ideas of De Vries and Johannsen, hope to find the key to evolution, since variations can not be the starting point for permanent changes. Examining a plant (*Œnothera lamarckiana*), De Vries thought he had found this key in abrupt transformations succeeding one another in organisms, under conditions which he has not been able to determine and which remain mysterious. The abrupt and immediately hereditary variations he named *mutations* and set them in opposition to *fluctuations* (i. e., common variations). According to him, evolution is not continuous but operates through mutations. The theory of mutations has been, since 1901, the occasion of an enormous number of experimental studies and of controversies, into which I shall not enter at this time, but I shall finally endeavor to extract the results won by this method of work. Let us note that, if De Vries and the mutationists do not formally deny the intervention of external factors in the production of mutations, the rôle of these factors is no longer very clearly or directly apparent, and some deny it more or less fully. In short, systematic study has led to an antithesis between *fluctuations* produced under the influence of the environment but not hereditary, and *mutations* not directly dependent upon the environment but upon heredity. We shall have to discuss the value of this distinction, the extent and the importance of mutations.

Another and very effective branch of research which has developed since 1900 and which dominates the study of biology just now, is the study of hybridization, which has led to the doctrine known as Mendelism. Sometimes the name *genetics* is specifically applied to it.

Toward 1860 the study of hybridization had led two botanists, the Austrian monk Gregor Mendel and the French botanist Naudin,[1] simultaneously but quite independently, to conceptions which did not particularly attract the attention of their contemporaries, but which were brought to light again in 1900, and which then formed the starting point of very many and important investigations. The experimental study of Mendelian heredity has been carried on, especially here in Harvard, with great success by Mr. Castle on various mammals and by Mr. East on plants. This topic, therefore, is familiar to the students of biology in this university. I shall speak of it for the present, only to state the general results. Let me recall to your minds as briefly as possible the essentials of Mendelism. According to this doctrine most of the properties which we can distinguish in organisms are transmitted from one generation to another as distinct units. We are led to believe that they exist autonomously in the sexual elements or gametes, and we can, therefore, by proper crossing, group such and such properties in a single individual, or, on the contrary, we can separate them. The biologist deals with these unit characteristics as the chemist does with atoms or with lateral chains, in a complex organic compound. The properties which we distinguish thus are nothing but the very indirect external expression of constituent characteristics of the fundamental living substance of the species. But we imagine, and it is in this that the enormous importance of Mendelism consists, that it has been the means of giving us a more precise idea than we have had heretofore of a substantial basis for heredity. In itself Mendelism is only symbolism, like the atomic theory in chemistry, but the case of chemistry shows what can be drawn from a well-conceived symbolism, and the Mendelian symbolism becomes more perfect each day in its form, in its conception, and in its application. The recent works of T. H. Morgan[2] are particularly interesting in this respect.

Further, the facts furnished by Mendelism agree well with those of cytology. The results are explained easily enough, if we accord to the chromatine in the nucleus, and particularly to chromosomes, a special value in heredity. The agreement of cytology and of Mendelism in incontestably a very convincing fact and a guide in present research.

But if we return now to the study of evolution, the data of Mendelism embarrass us also very considerably. All that it shows us, in fact, is the conservation of existing properties. Many variations which might have seemed to be new properties are simply traced to previously unobserved combinations of factors already existing.

[1] "Nouvelles Recherches sur l'Hybridité dans les Végétaux." Nouvelles Arch. du Mus. Hist. Nat., Paris, Tome 1, 1865, cf. p. 156.

[2] Cf. Morgan, Sturtevant, Muller and Bridges, "The Mechanism of Mendelian Heredity," New York, 1915.

This has indeed seriously impaired the mutation theory of De Vries, the fundamental example of the *Œnothera lamarckiana* seeming to be not a special type of variation, but an example of complex hybridization. The authors who have especially studied Mendelian heredity find themselves obliged to attribute all the observed facts to combinations of already existing factors, or to the loss of factors, a conception which seems to me a natural consequence of the symbolism adopted, but which hardly satisfies the intelligence. In any case, we do not see in the facts emerging from the study of Mendelism, how evolution, in the sense that morphology suggests, can have come about. And it comes to pass that some of the biologists of greatest authority in the study of Mendelian heredity are led, with regard to evolution, either to more or less complete agnosticism, or to the expression of ideas quite opposed to those of the preceding generation; ideas which would almost take us back to creationism.

Lamarckism and Darwinism are equally affected by these views. The inheritance of acquired characters is condemned and natural selection declared unable to produce a lasting and progressive change in organisms. The facts of adaptation are explained by a previous realization of structures which are found secondarily in harmony with varied surroundings. That is the idea which different biologists have reached and which M. Cuenot in particular has developed systematically.[1]

Two recent and particularly significant examples of these two tendencies are furnished us by W. Bateson and by J. P. Lotzy. In his Problems of Genetics, Bateson declares that we must recognize our almost entire ignorance of the processes of evolution, and in his presidential address at the meeting of the British Association in Australia, in 1914, he goes so far as to express the idea that evolution might be considered as the progressive unrolling of an initial complexity, containing, from the first, within itself, all the scope, the diversity, and all the differentiation now presented by living beings. As Mr. Castle cleverly expressed it, carrying the idea to its logical issue, man might be regarded as a simplified ameba, a conclusion which may well give us pause. Here we clearly recognize, on the other hand, modernized in form, but identical in principle, the conception of the "emboitement" of the germs, and of preformation, ideas to which, as I have reminded you, the eighteenth century applied the name evolution. It is a conception diametrically opposed to that of the transformism of the nineteenth century.

Mr. Lotzy, struck by the results of the crossing of distinct species of *Antirrhinum*, has reached in the last three years the conclusion that a species is fixed and that crossing is the only source of produc-

[1] Cuenot, "La Genèse des espèces animales," Paris, Bibliothèque Scientifique Internationale (Alcan), 1911.—"Théorie de la préadaptation," Scientia, Tome 16, p. 60, 1914.

tion of new forms. Hybridization among species, when it yields fertile offspring, may, according to him, give rise, all at once, to a whole series of new forms, whose mutual relations and differential characteristics correspond exactly to what the natural species show.

However subversive and delusive ideas of this kind, positive or negative, appear to generations saturated with Lamarckism and Darwinism, we must not lose sight of the fact that they were formulated by eminent biologists, and that they are the result of long and minute experimental researches and that many of the facts on which they rest may be considered as firmly established.

But without thinking of rebelling against the facts resulting from genetic studies, we may question whether they have so general a significance. I have already more than once pointed out that the present aspect of organic heredity does not oblige us to conclude that it has always been the same. We may ask ourselves whether conditions, which have not yet been realized in experiment, do not either modify directly the germinal substance itself, or the correlation existing between the parts of the soma, and indirectly through them the germinal substance. The facts which the study of internal secretions are just beginning to reveal, perhaps indicate a possibility of this kind. Even if we admit that evolution proceeds only discontinuously by mutations, we still have to discover the mechanism of the production of these mutations. In short, we may believe that, with heredity and variations acting as recent researches have shown them to act, there are nevertheless conditions that are still unknown and that they have been realized for each series of organisms only at certain periods, as seems to be suggested by paleontology, and in which the constitution and properties of hereditary substances are changeable. Of course these are purely hypothetical conjectures, but such conjectures must be made if we wish to reconcile two categories of already acquired data which we are obliged to recognize as facts. On the one hand we have the results of modern genetics which of themselves lead to conceptions of fixity, and on the other hand, the mass of morphological data which, considered from a rational point of view, seem to me to possess the value of stubborn facts in support of the transformist conception; I will even go so far as to say in support of a transformism more or less Lamarckian.

It seemed to me necessary to devote the first meeting of the course to this general analysis of the conditions under which the problem of transformism now presents itself. I believe that this analysis is the justification of the course itself. It shows the advantage of confronting in a series of lectures the old classic data with the modern tendencies, all of which have to be brought into agreement. The crisis of transformism which Le Dantec announced some eight years ago is very much more acute and more in evidence now than it was then.

SOME CONSIDERATIONS ON SIGHT IN BIRDS.[1]

By Dr. J. C. Lewis,
R. A. O. U., Melbourne.

[With 5 plates.]

That continual adjustment, so necessary for life, between internal relations of an organism and the external world would be impossible were it not for the communion of the sense organs. They stand, as it were, midway between the organism and its surroundings, keeping the internal relations aware of and alive to the external happenings and conditions. These functions probably arose with the necessity for adaptation to environment and its ever-changing demands, and in the struggle for existence they are necessary factors for the survival of the race.

Of the different special senses, hearing and sight stand apart in the degree of specialization, and this specialization, again, varies greatly in the divisions of the animal kingdom. In the animal world, for example, we find all stages from blindness to acute vision. Where the sight is poor, smell and hearing are, in compensation, extremely acute. The vision of the rhinoceros is limited to some 50 yards or so and is poor even for that short range, but the acuteness of the sense of smell makes good the sight deficiency. In birds specialization of sight reaches its highest degree of development; and though hearing is fairly acute, the sense of smell is certainly vestigial. One feature of the functions of hearing and sight is the projection of their sensory impulses. Taking sight, we find that light reflected from a distant object is picked up by the cornea and lens and brought into focus at a point on the retina. The stimulation of the numerous endings of the optic nerve sets up an activity which, after passing through many systems of relays, reaches the sight centers in the brain, giving rise to a complex chemical action in the cells, where the myriad impulses are figured out into a light pattern in the image of the original object. Though the action setting up these impulses originates in the brain, where the image is really

[1] Reprinted from the Emu, Vol. 15, Pt. 4, April, 1916.

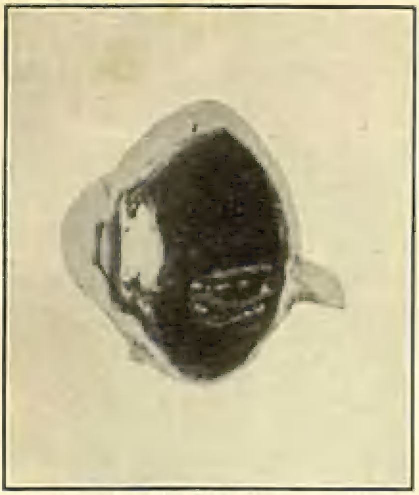
synthetized, the sensation is projected to the object from which the light is reflected. A similar projection occurs with the function of hearing, though perhaps not so definite in its localization.

If we consider the eye as an optical apparatus, looking at it from a mechanical point of view, we find that it can be likened with advantage to a camera, the convergence of rays being brought about by the lens and the cornea, the retina taking the place of the sensitized plate. This convergence of the diverging rays of light into focus on the retina from objects at varying distances is termed accommodation and corresponds roughly to the focusing of a camera. The process of accommodation differs greatly in the different classes of the animal kingdom. In terrestrial forms, where there is media of very much less density outside the eye—namely, the air—the principal convergence is done by the cornea, the outer transparent covering of the eye, the amount of convergence depending upon the laws of refraction governing light passing from a less dense to denser media.

Though the lens also acts to a lesser extent in the same way, the corneal convergence is the more important in these forms, the special important function of the lens being the alteration of focus. On the other hand, in aquatic forms, such as fish, no corneal convergence, or almost none, is present, the media—namely, sea water, or even fresh water—being of practically the same density as the media of the eye itself. In these forms convergence must, therefore, be brought about by the lens only, and for that purpose a spherical lens is present.

The physiology of accommodation in birds is remarkably complicated, differing in many respects from that found in the mammals. In the latter, or to be more correct, in the terrestrial forms alteration of focus is brought about by alteration in the shape of the lens. This structure when focused for near objects becomes more convex, particularly on the anterior surface. There is no change in shape of the transparent front part of the eye. In birds, on the other hand, with the exception of some of the night fliers, though like in man and other animals, the eye is normally focused for distance, accommodation is a more complex process, there being change in shape both of the lens itself and of the eyeball as a whole. It further differs in that it is a positive process, relaxation of the muscle focusing the eye for nearer points.

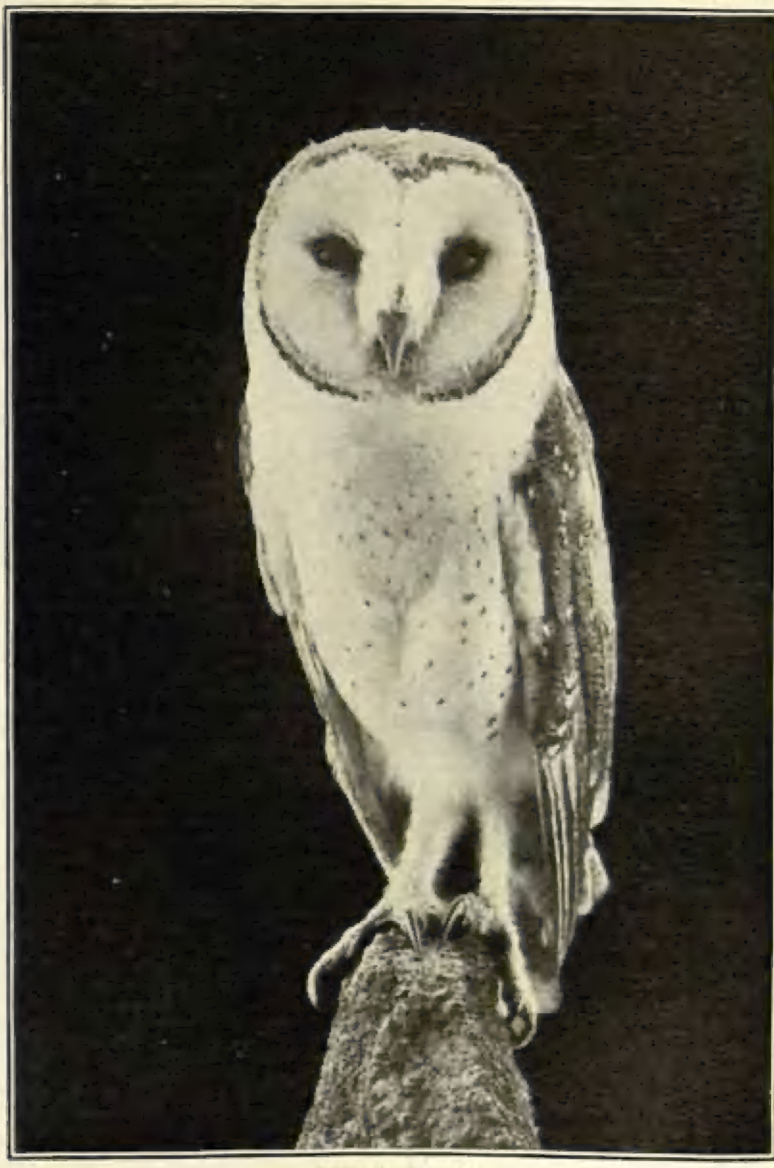
In birds there are found two main types of eyes, though intermediate forms exist—namely, the tubular eye, with rounded lens, which allows for a normal near vision such as in the night-flying birds; and the other, the almost spherical eye, with flattened lens, characteristic of high-soaring birds of prey, and consequently adapted for distant vision (pl. 1).



1. Eye of Emu dissected to show anterior and posterior chamber of globe, showing well-developed pecten, almost spherical eye, flattened lens. Type of eye normally focussed for distance.

2. Globes of the eye of a Horned Owl. Skull dissected away to show comparative size of eyes to the brain. Cornea removed from right eye. Specimen shows the tubular eye of near-sighted night birds, the eyes capable of forward vision, both seeing practically the same field of vision.

3. Plain Wanderer. Type of total monocular vision. Both visual fields distinct.



AUSTRALIAN BARN OWL.

Showing eyes capable of forward double vision.

NANKEEN KESTREL.

Showing eyes capable of seeing a single object with both eyes, though total visual fields vary greatly.

CRESTED PIGEON.

Vision totally monocular, both visual fields differing, either eye capable of suppression in concentration of the other eye on a single object.

There is little to be said of the iris in birds apart from the fact that the movement of this curtain or diaphragm is voluntary, the pupil widening or closing at will. Apart from the voluntary action, closing of the pupil or a stopping-down process occurs in the presence of strong light, and is, therefore, reflex in nature, widening of the pupil being noticed in weak light and also for distant vision.

The retina—the sensitive plate, as it were, of the eye—consists of a layer of fine nerve endings which in most animals conform to two well-marked types—rods and cones. In birds it has been for a long time thought that this layer consisted of rods only, but closer examination shows that cones are present, though very much reduced in number. There is also a belief existent, with perhaps some reason, that the function of the cones is associated with differentiation of colors or the formation of visual purple, while rods determine movement, form, and shape. This is the layer which is stimulated by the photo-chemical action of light, the sensitizing substance being found in the external layer of the retina and called, for convenience, visual purple. It is believed that this substance changes under the effect of light, and the chemical changes effected act on and stimulate the nerve endings, giving rise to the particular sensation. In vertebrates this retina is not without its drawbacks. There is a well-marked blind spot where the optic nerve branches out into its numerous endings, this area being particularly large where the pecten is well developed. Further, many blood vessels ramify over the surface of the retina, and here, also, light is prevented from falling on and being registered by the sensitive layer.

It is well known that in man there is a central small area where sight is keenest. This is called the *fovea centralis*, and here only rods are present. In birds it is believed that there are two such areas in each eye, one on either side of the pecten. It may be stated here that the pecten is a pigmented, vascular structure lying in the posterior chamber of the eye, protruding forward from the papilla of the optic nerve (pl. 1, fig. 1). The size varies considerably in different species, extending in some almost to the posterior surface of the lens, while in others it is small and inconspicuous. It is absent in one bird—namely, the Apteryx—and is practically absent in the Nankeen night heron (*Nycticorax caledonicus*). The function of the pecten has always been a matter of controversy. There seem to be no special habits or conditions in birds possessing this structure of equal size and shape, while birds with similar habits show great variations. One theory was that it was protective, guarding the retina from the action of excessive light, in other words, a light filter. Its structure being vascular suggests some functions associated with the tension or nutrition of the eyeball. In accommodation for near

objects it has been found that there is, with the passage backward of the posterior surface of the cornea, the transference of fluid from the anterior chamber. This is shown by injecting methylene blue into the anterior chamber and stimulating the nerves of accommodation, then noting the course of the fluid.

Admitting then that there is a transference of fluid from one chamber to another to maintain an unvarying intraocular pressure, some governor must be present to effect this quick interchange, and it is believed that the pecten acts in this way. In support of this theory it can be shown that in high-flying birds, birds of rapid flight, birds of prey where the eyes have to be accommodated to extremely rapid alteration of focus, the pecten is well developed. It is, on the other hand, comparatively small in nocturnal birds. Against this theory it may be stated that reptiles, or some reptiles, possess a pecten, and in these animals the above conditions hardly exist. The important point is that the presence of this large pecten creates a large blind area in the eye, and as it is heavily pigmented all light falling on it is naturally absorbed. It explains to some extent the constant shifting of the head when a bird is on the watch, as the visual field is considerably limited, the portion obstructed being toward the upper outer field of vision. Before leaving the retina it should be mentioned that the presence of oil globules in this layer has been known for a long time. These globules are colored red and yellow and are found only in birds. They appear to exert no effect on color vision, as they are in no way identical in composition with the visual purple or sensitizing substance.

The numerous fibers from the endings of the rods and cones collect to form the optic nerves. The nerve from each eye converges and meets at what is known as the optic chiasma, where they unite and again separate. In all animals where binocular vision takes place, or to be more correct, whêre there is total binocular vision, there is partial decussation of the fiber. Those fibers leading from the right half of the right eye pass to the right side of the brain, while the fibers from the left side of the right eye cross over at the chiasma to the left side of the brain.

The amount of decussation varies accordingly with the power of binocular vision. In some animals where partial binocular vision is possible, though not usual, as in the horse and some rodents, only a few fibers do not decussate. In animals incapable of any binocular vision complete decussation takes place. This latter condition is found in birds, or nearly all birds, the fibers entirely crossing over at the chiasma. One must first get a grasp of the true meaning of binocular vision to appreciate the difference between pure binocular vision and seeing the same object with both eyes. If we hold a piece of paper between the eyes so as to view, say, a red area with the

right eye and a yellow area with the left, we do not see the two separate colored spots, but a spot of the color equalling the blending of the pigments; this is due to a superimposing of the images registered. In animals and birds where the axes of the eyes are not parallel it means that the image of an object falling on the right half of the right eye falls on the left half of the left eye. Only in animals where the axes of the eyes are parallel do the images fall on the same half of each eye, notably in human beings and monkeys, thus making possible true binocular vision. In other words, in birds, with the possible exception of some of the birds of prey and some nocturnal birds, the sight or visual field consists of two separate views not capable of being superimposed and not stereoscopic in effect.

The advantage of observing the same object with both eyes is that it permits of greater concentration once an object or victim has been perceived, and it is thus found in eagles, hawks, etc., where acuity and concentration are so necessary for their existence. In man the stereoscopic vision gives him the judgment of distance, and it is chiefly by this and, to a smaller extent, by accommodation, that distance is accurately estimated. On the other hand, birds, or most birds, have to depend upon accommodation for their judgment of distance possibly by the focusing movement of the lens brought about by the action of Crampton's muscle, the pull being so strong in some species that a ring of bony laminæ is provided in the sclerotic coat near the corneal margin to prevent alteration in shape of that part of the eye.

Monocular vision has a great advantage of giving a far more extensive scope of vision. It is a valuable asset for the birds which must maintain a constant lookout for the approach of danger, and for that reason it is found mainly in those birds of poor defense, whose safety lies in speedy detection and evasion of their enemies. In these birds there is the range of two extensive visual fields, each being equally recorded and scrutinized. The moment an object of interest is detected the bird does not direct both eyes toward it, but there is a concentration of one eye, the vision of the other being suppressed at will. In some diseases of man, where the axis of one eye has departed from the parallel of the other, each eye sees a field which does not correspond with the other, yet diplopia, or double vision, is not present, as the one or the other field of vision is suppressed according to the automatic concentration in one or the other eye. Note a group of pheasants or pigeons watching the same object; one eye only will be directed toward the position. Watch a fowl or a pigeon gazing upward at a hawk; one eye will be skyward, the other toward the ground. In such cases the vision of the downward eye is being suppressed. If suppression were not possible in birds a position similar to diplopia would be present. An idea of this condition can be gained by pressing one's eye, thus shifting the

visual axis of one eye, when a double image is obtained. In the human it is possible to suppress the vision by exercise and education, otherwise the eye must be closed—thus, in shooting or looking down a microscope—but by a continual effort at concentration it is possible to keep both eyes open and to suppress the vision of one.

When we come to acuity of vision in birds one must immediately recognize a superiority over the rest of the animal kingdom. There is no doubt that they possess an acuity almost immeasurable compared with our own standard. Normal sight in man gives an acuity of about 1 minute in degrees of the circle, which means that at 6 meters we can distinguish clearly enough to identify letters in lines 1 centimeter in width. Man and monkeys are perhaps in advance of the rest of the mammals, but fall extremely short of the standard found in birds. Speaking roughly, it is justifiable to say that birds possess about a hundred times the degree of acuity found in man. Visual acuity for moving objects is much more keen. This probably accounts for the habit of small animals or birds wishing to escape detection becoming immobile, their protective coloring blending with the surroundings.

Peep through the smallest hole in a fowl-yard fence, and one will find that some old hen has perceived the action. An instance of the remarkable visual acuity can be seen in the vulture and its habits. On the death of an animal there may not be a vulture in sight, and in a few hours' time many will have arrived at the feast. These birds become aware of a dead beast not by smell (as that sense is vestigial), but by sight. Vultures are extremely high fliers, only one bird outsoaring them—namely, the adjutant. It is probably that the nearest vulture sights the animal and descends to the carcass. The bird's action is observed by the vulture farther away, which is likewise led to the scene, and so it goes on. In this way it is believed that birds come from a distance of from 50 to 100 miles by their observation of each other's action. A fact pointing to their ability to locate a carcass was observed in one of the outbreaks of rinderpest in Natal. It was found that if a carcass were covered by branches immediately after death, so as to obscure it from the sight of the birds, it was never disturbed by vultures.

Though there is no means of measuring accurately the visual acuity of birds, a fair idea may be obtained by observation of their habits. A great brown kingfisher (*Dacelo gigas*), from a position on a post where it can inspect newly plowed land, seems to have no difficulty in locating the exposed part of a worm from any distance up to 100 yards. Watch an old hen in charge of a few chicks, and nothing overhead, be it ever so small, will escape her notice.

Acuity for stationary objects, though not so finely sensitive as for those moving, is still remarkable. Experiments have been made with

pigeons, feeding them on a board on wheat, among which a percentage of the grains have been stuck by adhesive substance. One mistake is sufficient to prevent them again making the error, small, slight alteration from the natural position of the grain giving them the clue. Many similar cases could be quoted. The vision of nocturnal birds is enhanced by the size of the eyeball itself and the convexity of the cornea, which collects more light from an object than that with less convexity. They present, too, the markedly tubular eye. The pupil in these birds is capable of great dilatation. The poorness of vision of these birds in the daytime is accounted for by the fact that the eye is normally focused for objects comparatively near and, again, because of the amount of stooping down necessary to exclude the strong light. The eyes of these birds are probably what are known as dark-adapted eyes, and the attempt to see in bright sunlight has an effect similar to that which we experience on emerging from a dark room into the sunlight. This is not due so much to the contraction of the pupil as to arrangement of the protective pigment around the endings of the optic nerve.

The power of individual movement of the eyes is greater in birds than in man, extensive divergent movement being possible, while convergent movement is seen as in the human being. But, in spite of this, the amount present is not sufficient for the needs of the bird, which nearly always moves the head to shift the direction of gaze.

Of the accessory structures of the eye not much need be said. The eyelids present little differing from mammals, with the exception of the absence of eyelashes and the greater mobility of the lower lid. The third eyelid, known as the nictitating membrane, is well developed in birds, constantly sweeping the surface of the cornea and keeping it free of small particles, etc. In mammals it is not moved voluntarily, but by pressure exerted by the backward movement of the eye itself. This membrane in birds is moved by two voluntary muscles, which bring it across the eye with lightning-like rapidity. In aquatic birds it invests the eye while submerged, and is then transparent, to allow vision without endangering the sensitive surface of the globe.

We come now to a more interesting though more difficult problem—that of color vision. If one accepts the Young-Helmholtz theory, it must be taken that white light consists of the combination of three primary colors, namely, red, green, and violet. Later works seem to incline toward the older division according to Newton—that the primary colors included red, orange, yellow, green, blue, indigo, and violet. In other words, the blue and yellow have as much right to be considered as primary colors as the other three. The existence of color vision in animals is, of course, very difficult to

determine. It appears, however, that with trained dogs and horses there is no difficulty at all in teaching them to distinguish between the saturated colors. The preference of some birds, notably the Bower Birds, for objects of a certain color and the general evolution of color in the different species must point to an appreciation of different shades. Color sensation must be appreciated by the stimulation of waves of varying lengths. In man it varies from about 770 μ to 396 μ, the latter being the extreme of light registered at the violet end of the spectrum.

It would appear, if we adopt the Young-Helmholtz theory, that man has a trichromatic vision, and that all the shades appreciated are due to the degree in which the three classes of nerve fibers are stimulated. Yellow, for example, is caused by an equal stimulation of the sets of fibers for the red and green percipients. When red is seen the fibers percipient of red are strongly stimulated, the others only weakly. Color blindness is an interesting side study in this respect, particularly when we come to the color vision of birds. In man dichromatic vision appears most commonly with a blindness for red or green, the violet blind being rare. In red or green blindness the subject confuses reds and greens, and in a mixture of colors including these colors other than red or green are the only ones appreciated.

Now, it has been shown by feeding experiments that birds are blind in the violet end of the spectrum. In other words, if we accept the Young-Helmholtz theory they have a dichromatic vision. Their color vision would be restricted to red and green and the mixtures of these colors. They would be blind to violet and to the spectral violet in blue, indigo, and yellow. Such a conclusion would be disastrous to our theory of selection in the coloration of birds, where many blues and shades of blue are seen. It would mean that the development of color in the evolution of the present-day bird was merely incidental and apparently without reason. The flaw in the reasoning probably lies in our acceptance of the Young-Helmholtz theory instead of recognizing the other colors as primary. Again, the conclusion obtained from the feeding experiments may be faulty. The birds are fed in spectral red light and in spectral green, where they pick up the grains readily; but when taken to spectral violet remain still, fail to see the grains, and are to all intents and purposes in darkness.

A man color blind in red or in green, though not seeing these colors as a normal person would see them, still sees the objects, but is blind to the color only. His vision extends right to the red end of the spectrum, though not recognizing the red there, so that the waves stimulate the eye, though not giving the color sense. It is probable that in birds the sight is keyed to a higher pitch than in man, and

that the retina is not stimulated by wave lengths as short as that of the violet, while yet possessing the whole of the range of colors as far as the violet. In man we know that the eye is blind beyond the two limits of red and violet, but we are able to ascertain the presence of ultra red and ultra violet rays that the retina does not register.

There is still a great field for investigation into the function of sight. So far the work done is mainly comparative, and must be based on the lines found existent in the human subject, where the subjective assistance is of great value. But of the conditions in birds we can only theorize, while there may be present conditions outside our comprehension of the powers of the eye. There is still much to be learned concerning accommodation, monocular vision, color vision, and the function of the pecten.

PIRATES OF THE DEEP—STORIES OF THE SQUID AND OCTOPUS.

By Paul Bartsch,
Curator of Marine Invertebrates, U. S. National Museum.

[With 19 plates.]

INTRODUCTION.

The largest, the most highly organized, as well as intelligent, and therefore, most interesting invertebrate creatures of the sea belong to the class of organisms known as Cephalopods, a group of marine mollusks embracing the Nautilus, Squid, Cuttlefish, Octopus, Argonaut, as well as the Nautiloids, Ammonites, and Belemnites of the ancient seas.

The old forms, geologically speaking, as far as known, were all shell-bearing organisms. Their changing from the cramped condition of an inclosing and confining exoskeleton or shell to an endoskeleton or pen, or even no skeleton, came only in very recent times and carried in its train of development not only possibilities of bodily expansion, as shown by the giant squid of our seas, but produced even greater and far more important consequences, namely, the development of a highly specialized brain, which to-day easily places this group in the first rank of all the invertebrate dwellers of the sea when viewed from the standpoint of mentation.

Compared with our squids, the chambered Nautilus, the relic of the most ancient stock, is an extremely stupid animal.

PAST HISTORY.

In order to follow the customary line of the biographer, we must first give a bit of attention to the ancestors of our subjects and to this alone one might well devote the entire space allotted to our sketch. Paleontology has taught us that these wonderful creatures

can boast of a long line of progenitors; indeed, there are few groups that can compare with them in this respect. For millions upon millions of years ago, or to be more precise, in Upper Cambrian times, there existed a small nautiloid animal in the seas, whose deposits are known as the Chau-mi-tien limestone near Tsi-nan, Shantung, China. The shell of this little animal, which was christened *Cyrtoceras cambria* by Dr. Walcott in 1905,[1] is only 7 millimeters in length and 3 millimeters in diameter (fig. 1).

Ever since that time, and probably long before this tiny, flexed, but noncoiled chambered nautiloid ancestor of the Cephalopoda existed, chambered nautili were living somewhere in our seas. The Ozarkian period ushered in a number of families, each with its genera and species. The Canadian added materially to these, but the greatest differentiation of all took place in the Ordovician and Silurian, after which the decline of the order began, resulting finally in the remnant of four closely allied species belonging to the single now existing genus Nautilus. In all, about 3,000 species have been named and to their number new forms are constantly being added by the patient paleontologist. In all these forms we have the shell divided into chambers by transverse concave septa whose margins may be straight or undulate; a siphuncle or tube extends from chamber to chamber connecting them with each other. The range of variation in shape and size is quite great. There are straight cones, as in Orthoceras; flexed forms, as in Cyrtoceras; loosely coiled forms, as in Sphyradoceras; closely coiled forms, as in Nautilus; or even closely coiled and finally solute shells, as in Ophidioceras and Lituites. The sculpture, too, presents no end of variations, for some shells are smooth, others axially or spirally striate, or channeled; or lirate, or threaded, ribbed, or keeled, or marked by combinations of these elements, some even have tubercles and bosses, but whatever the sculpture or size, which varies from the 7-millimeter ancestor to the 14-foot or more long cones of Endoceras, one word characterizes the entire group, and that is elegance (pl. 1).

FIG. 1.—*Cyrtoceras cambria* Walcott. The ancestor of the Cephalopoda. Side view, X 5. End view, X 7.

During the Upper Silurian period a new offshoot of the Cephalopod stock developed, a stalk which has far excelled the Nautiloids in numbers as well as in diversity of structure. We refer to the order Ammonoidea, "the Ammon's horns," of which probably more than

[1] Proc. U. S. Nat. Mus., Vol. 29, p. 22, 1905.

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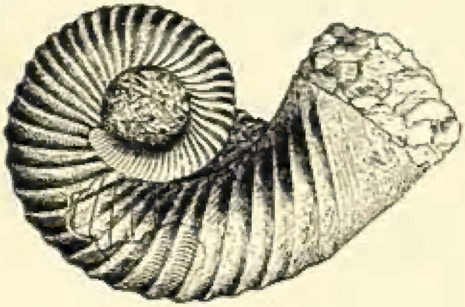

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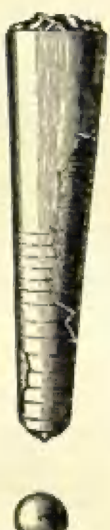

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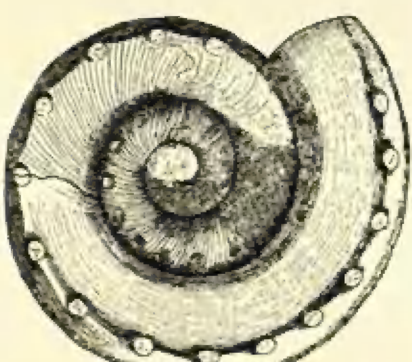

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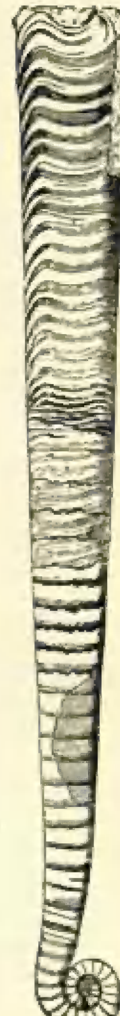

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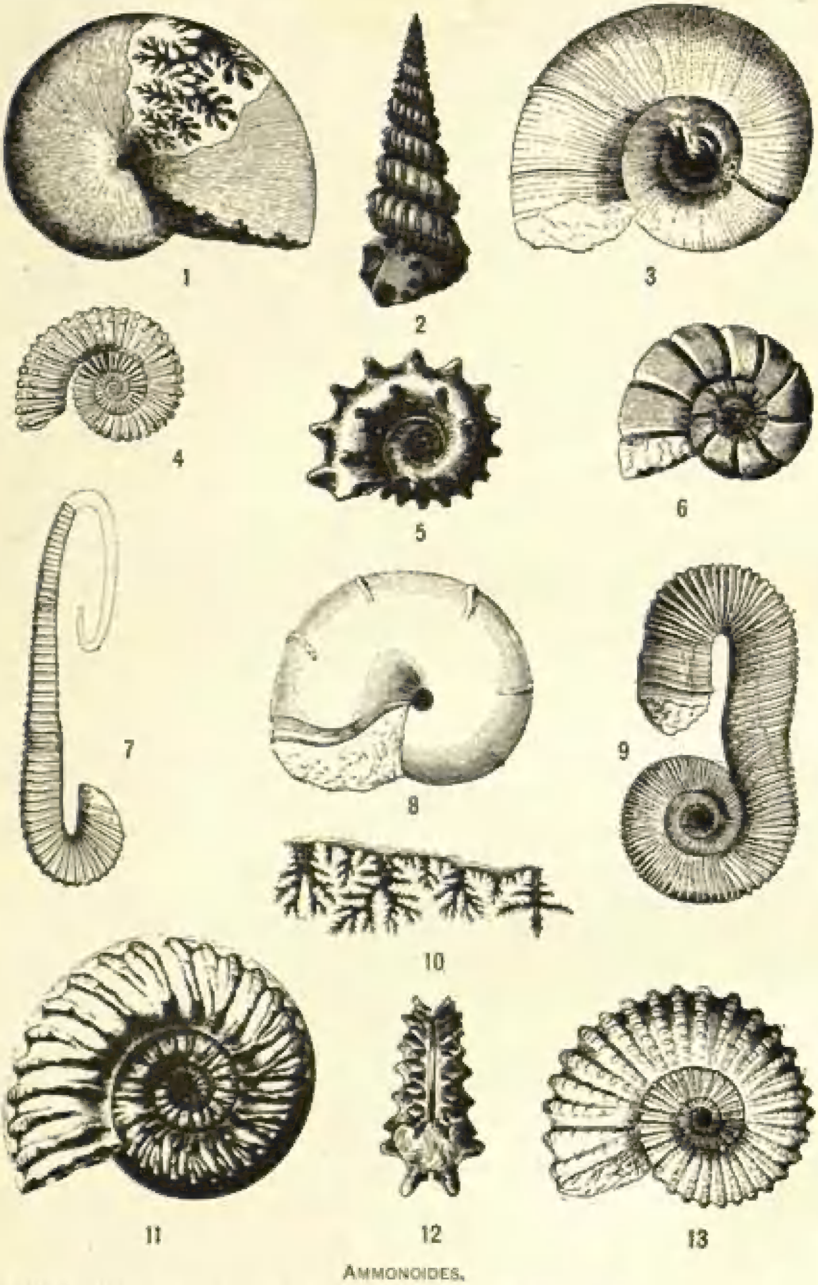
NAUTILOIDS.

1. *Thoracoceras corbulatum* (Barrande). 2. *Sphyradoceras opiatum* Barrande. 3. *Ophidioceras simplex* Barrande. 4. *Endoceras timidum* Barrande. 5. *Hercoceras mirum* Barrande. 6. *Lituites lituus* Montf.



AMMONOIDES.

1. *Phylloceras heterophyllum* (Sowb.). 2. *Turrilites catenatus* d'Orb. 3. *Lytoceras liebigi* (Oppel.). 4. *Choristoceras marshi* Hauer. 5. *Hoplites tuberculatus* Sow. 6. *Aioelytoceras germainei* (d'Orb.). 7. *Hamites rotundatus* (Sowb.). 8. *Phylloceras ptychoicum* (Quenstedt). 9. *Macroscaphites ivanii* (d'Orb.). 10. Septa of *Lytoceras liebigi* (Oppel.). 11. *Mortoniceras inflatum* Sow. 12. *Hoplites tuberculatus* Sow. 13. *Douvilleiceras mamillare* (Schloth.).

6,000 species are known. Here form, complexity of septation, and external sculpture ran riot, or, may we say, attained an overspecialization which soon spelled exit, for the group reached its highest development in the upper Trias and disappeared suddenly and completely at the close of the Cretaceous. In size their shells vary from the dimension of a pea to more than 6 feet in diameter. Plate 2 will give the reader a little more intimate view of the group.

The third order, Belemnoidea, of the Cephalopoda, is of considerably less antiquity, dating back only to the Triassic period with not a single living representative, for the little chambered Spirula has been definitely disposed among the modern 10-footed members, though the paleontologists still classify it with the Belemnoidea. It is among these Belemnoids that we have to seek the ancestors of our squids and cuttlefishes for, like them, they have an internal shell, but of much greater complexity. They also possessed the ink bag, a character present in all our modern Cephalopods excepting the Nautilus. It is quite possible that these members were as abundant in these later seas as their ancestors were in their time and as their descendants are to-day, but they had little of fossilizable material to leave behind them at death, and thus have left a rather poor, scattered, and fragmentary record of their existence. Judging from some of the pens, however, it is well to assume that the soft body inclosing them may have compared favorably in size with the members of the now existing fauna. Some of these pens are called fossil "thunder bolts" by the uninitiated. Plate 3 shows a selection of these remains.

We next come to the modern dwellers of the seas, our "pirates of the deep." In these we have either an internal skeleton or none at all. In the squids the shell is embedded in the dorsal part of the mantle and frequently reduced to a mere chitinoid remnant, called the pen (pl. 4, fig. 1) from its resemblance to the quill pens of old. At times this is decidedly reinforced by calcareous material, as shown by the cuttlebone (pl. 4, fig. 2) which we are accustomed to furnish our canaries, for this is the skeleton of our cuttlefish. The only coiled or chambered test is found in Spirula, but here it serves not as a container, but is contained within the mantle. The shell of the beautiful Paper Nautilus or Argonaut is not a skeletal shell at all, but a mere case used by the female for the protection of her eggs.

In all these animals the body is enveloped in a soft mantle. The head is strongly differentiated from the rest of the body and is surrounded by a circle of 8 or 10 sucker-bearing arms or feet which, in reality, are modified elements of what corresponds to the anterior part of the foot in other mollusks. It is the position of these feet about the head of these animals that has gained for them the name

Cephalopoda, head-footed. The mouth is situated in the middle of the tentacular disk and is armed with a pair of formidable parrot-beak-like jaws. Not least conspicuous are the two large, highly specialized eyes situated on the side of the head. Behind the head is a constricted neck. Here we find a cleft, the communicating orifice between the exterior and the mantle cavity; here also is inserted the tubular siphon which, in reality, is the modified posterior part of the foot and serves as the chief organ of locomotion, for much of the Cephalopod swimming is accomplished by the rapid expulsion of water through this organ by means of the sudden contraction of the muscular mantle.

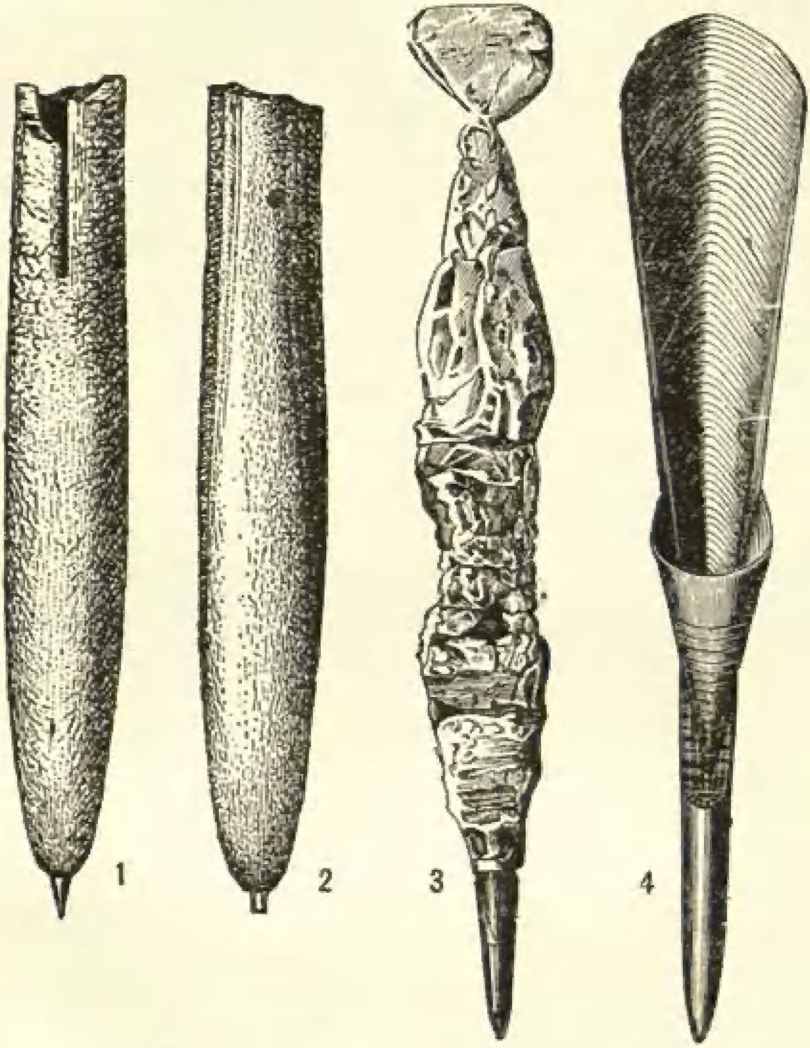
The posterior portion of the body may be globular, conic, spindle, or lance shaped, or cylindric; it may or may not have lateral flukes, which may serve as organs of locomotion; or may be modified to form a sucker, as in Spirula. The internal organization is also interesting, but we shall content ourselves with the simple statement that the sexes are distinct and that the rather complex brain is shielded in most of them by a cranial cartilage that protects the principal nerve centers, incloses the auditory organs, and supports the very highly developed eyes. An interesting structure found in all the living forms, except the Nautilus, is the ink bag, a glandular sac and a reservoir connected by a duct with the rectum near the anus. This organ produces a dark fluid which the animal is capable of discharging at will. It is usually ejected when the animal is pursued and effectively enwraps it in an impenetrable smudge, thus aiding it to make good its escape. The secretion of the Cephalopod ink bag forms an important element of commerce and our arts, where it is better known under the name of sepia and india ink.

The living Cephalopods, excepting the Nautilus, are easily divided into two groups or orders. One of these, Decapoda, embraces all the members having 10 feet, while the members of the other order, Octopoda, have but eight (pl. 5).

Beautifully preserved specimens of squids have been found in those remarkable reliquaries, the Solenhofen lithographic limestone deposits of Bavaria, the hardened ooze of an ancient sea, which has contributed so many chapters to our knowledge of the past. These remains proclaim the presence of the order in the Lower Jurassic. Plate 6 is a photograph of a specimen, U. S. Nat. Mus. Cat. No. 28382, which comes from this formation at Eichstatt and shows the perfect manner in which the soft, enfolding ooze has preserved its record for us.

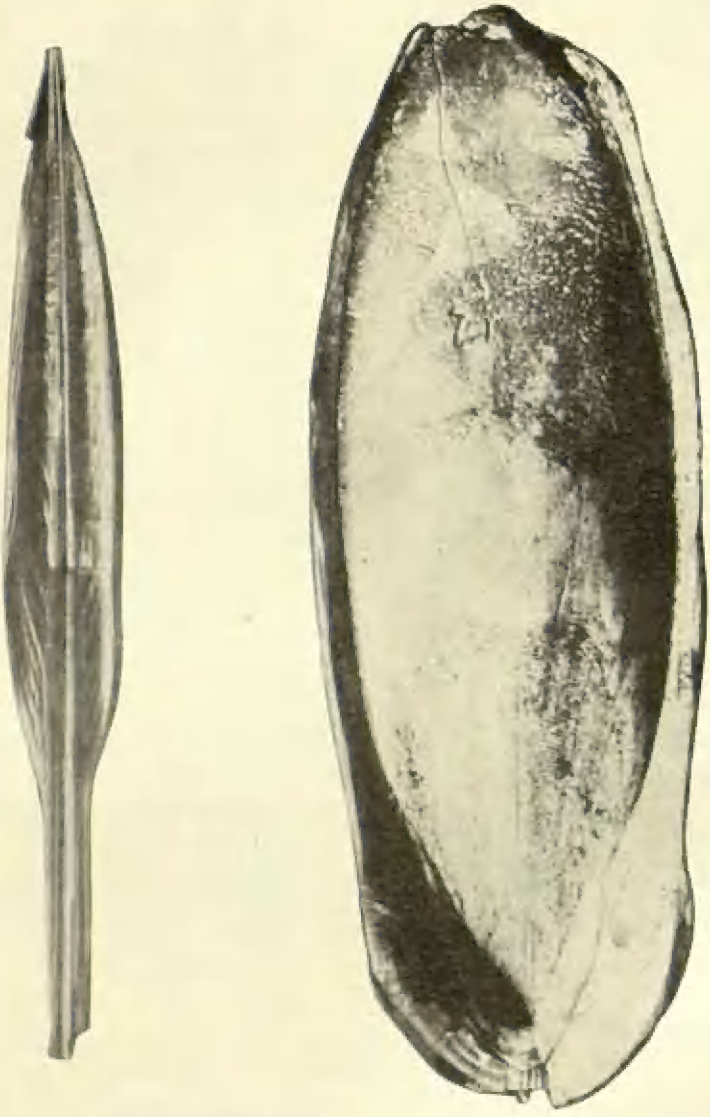
FACTS AND FANCIES.

Size, power, speed, beauty, and intelligence have ever been the elements that have elicited the admiration of man. Add to this the



BELEMNOIDS.

1 and 2. *Belemnites mucronatus* Schloth. 3. *Belemnites brugierianus* Miller.
4. Restoration of same.



1 2

INTERNAL SHELLS OF MODERN SQUIDS.

1. *Loligo vulgaris* L. 2. *Sepia officinalis* L.

mystery of the sea and the toothsomeness of our beasts, and you have a setting with possibilities that seek a rival. No wonder, then, that we find the ancient writers and bards and all those of years between them and our modern penman singing songs and spinning yarns about our Cephalopods, for they possess all the qualifications denoted above. Passing through the literature of the ages, one finds myths and fancies so wonderfully intertwined with a basis of facts, that even the knowing, prosaic but incisive naturalist finds it difficult to pass judgment on what is fact or fiction. One thing, however, is certain, and that is that all the legends and myths appear as clumsy sailor yarns when compared with the facts which are being slowly revealed by the painstaking students of the group.

The early writings frequently combine in their discussion of some one of these animals, characteristics that belong to widely different orders. Not only that, but the earlier authors even assigned to the Physalia or Portuguese Man-o'-War, and the beautiful little Velella, attributes belonging to the Argonauta and the Chambered Nautilus, for the fairy sails that were assigned to these animals are undoubtedly the wonderfully colored floats of the lowly organized Hydrozoans (pl. 7).

We quote from Pliny:

THE NAUTILUS, OR SAILING POLYPUS.

Among the most remarkable curiosities is the animal which has the name of Nautilus, or, as some people call it, the Pompilos. Lying with the head upward, it rises to the surface of the water, raising itself little by little, while, by means of a certain conduit in its body, it discharges all the water, and this being got rid of like so much bilge-water as it were, it finds no difficulty in sailing along. Then, extending backwards its two front arms, it stretches out between them a membrane of marvelous thinness, which acts as a sail spread out to the wind, while with the rest of its arms it paddles along below, steering itself with its tail in the middle, which acts as a rudder. Thus does it make its way along the deep, mimicking the appearance of a light Liburnian bark; while if anything chances to cause it alarm in an instant it draws in the water and sinks to the bottom.

The Chambered Nautilus lives in the tropical western Pacific, usually at a depth of a hundred or more feet, and, all myths to the contrary, has never been known to sail the surface of the sea (pl. 8).

We quote more from the same authority, this time a story relating to a gigantic octopus:

At Carteia, in the preserves there, a polypus was in the habit of coming from the sea to the pickling tubs, that were left open, and devouring the fish laid in salt there—for it is quite astonishing how eagerly all sea animals follow even the very smell of salted condiments; so much so, that it is for this reason that the fishermen take care to rub the inside of the wicker fish kipes with them. At last by its repeated thefts and immoderate depredations it drew down upon

itself the wrath of the keepers of the works. Palisades were placed before them, but these the polypus managed to get over by the aid of a tree, and it was only caught at last by calling in the assistance of trained dogs, which surrounded it at night as it was returning to its prey; upon which the keepers, awakened by the noise, were struck with alarm at the novelty of the sight presented. First of all, the size of the polypus was enormous beyond all conception; and then it was covered all over with dried brine and exhaled a most dreadful stench. Who could have expected to find a polypus there or could have recognized it as such under these circumstances? They really thought that they were joining battle with some monster, for at one instant it would drive off the dogs by its horrible fumes and lash at them with the extremities of its feelers, while at another it would strike them with its stronger arms, giving blows with so many clubs, as it were; and it was only with the greatest difficulty that it could be dispatched with the aid of a considerable number of three-pronged fish spears. The head of this animal was shewn to Lucullus; it was in size as large as a cask of 135 gallons and had a beard (tentacles), to use the expressions of Trebius himself, which could hardly be encircled with both arms, full of knots, like those upon a club, and 30 feet in length; the suckers, or calicules, as large as an urn, resembled a basin in shape, while the teeth again were of a corresponding largeness; its remains, which were carefully preserved as a curiosity, weighed 700 pounds.

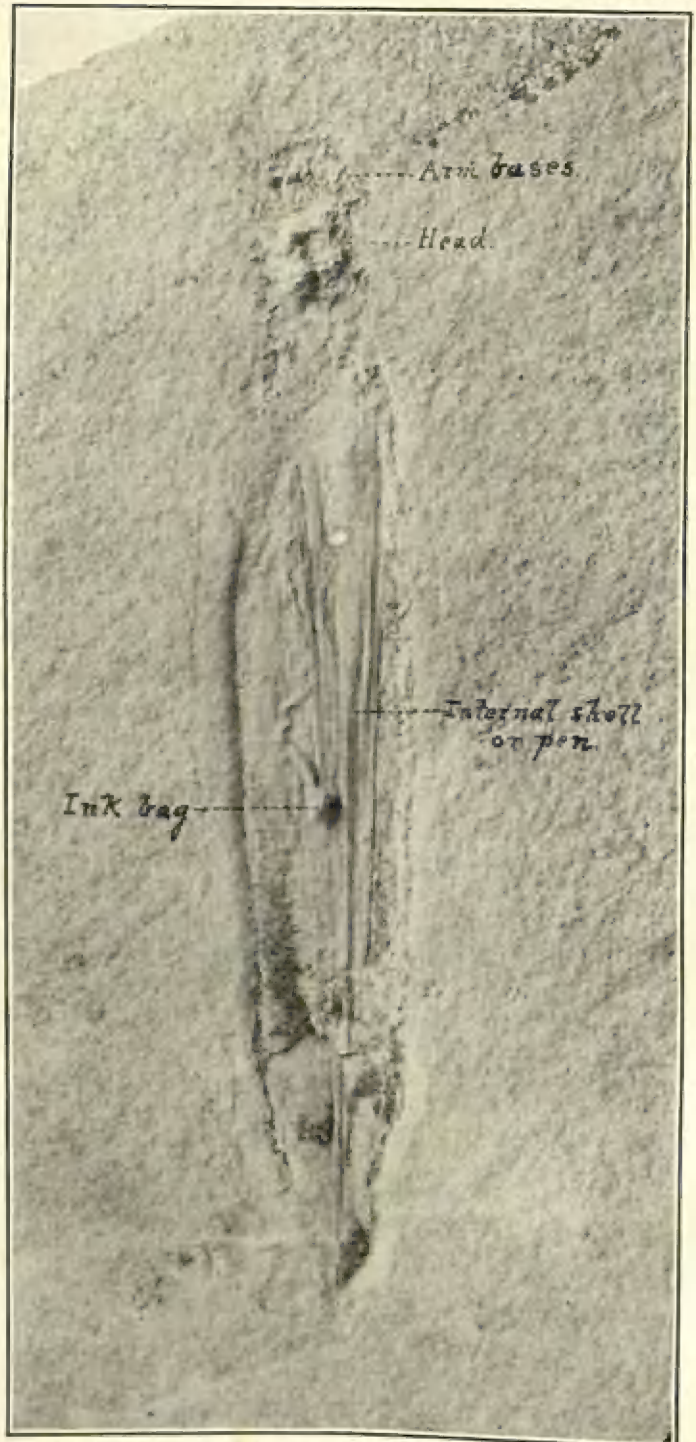
Denys Montfort, who spent many years in ardent study of Cephalopods and devoted a whole volume[1] to the publication of his results, cites numerous incidents of marvelous encounters between man and some of the larger members of this group. We shall quote a few selections:

An old captain named John Magnus Dens, who resided in Dunkirk, related that, sailing once between the isle of St. Helena and Africa, near the coast the ship was becalmed. He took advantage of this calm to send men over the side to clean off the grass which accumulates near the water line on long voyages. The men were standing on stages suspended near the water's edge, scraping with iron scrapers, when suddenly a huge cuttlefish appeared at the water's edge and, throwing one of his arms about two of the men, tore the unfortunates, with their stage, from the side of the vessel and dragged them into the water. At the same time it threw another arm about a man who was just mounting the main rigging; but here its arm became entangled with the shrouds and ratlines, and it was unable to disentangle itself. The man, who was being severely squeezed, cried out for help, and the crew immediately ran to his assistance. Several threw harpoons into the body of the beast, which was now rising along the ship's side; others with axes cut in pieces the arm which held the man to the rigging and took the unfortunate down on deck.

This done, the cuttle sank down, but the captain payed out on the lines which were fast to the harpoons, in the hope that presently he would be able to drag the beast up again and recover the two men who had been dragged down. In fact, at first he was able to drag the animal toward the surface; but presently the huge beast again sank down, and they were obliged to pay out line after line, till at last, having but a little left, they were forced to hold on; and now four of the harpoons drew out, while the fifth line broke, and thus all hope of saving the unfortunates or killing the monster was lost.

[1] Histoire Naturelle Des Mollusques, Tome 2, Paris, An. X.

AN OCTOPUS (OCTOPUS VULGARIS L.) CAPTURING A CRAB.



A FOSSIL SQUID FROM THE SOLENHOFEN LIMESTONES OF BAVARIA.

This should be followed by the illustration of the sailing vessel attacked by a huge octopus, also taken from Montfort, which is said to be a facsimile of a painting that he saw in the Chapel of St. Thomas, in St. Malos, a French seaport, and of which he relates the following story, told by some of the crew of the vessel to which the adventure it depicts happened (pl. 9):

The ship was on the west African coast. She had just taken in her cargo of slaves, ivory, and gold dust, and the men were heaving up the anchor, when suddenly a monstrous cuttlefish appeared on top of the water and slung its arms about two of the masts. The tips of the arms reached to the mastheads, and the weight of the cuttle dragged the ship over, so that she lay on her beam-ends and was near being capsized. The crew seized axes and knives, and cut away at the arms of the monster; but, despairing of escape, called upon their patron saint, St. Thomas, to help them. Their prayers seemed to give them renewed courage, for they persevered, and finally succeeded in cutting off the arms, when the animal sank and the vessel righted.

Now, when the vessel returned to St. Malos the crew, grateful for their deliverance from so hideous a danger, marched in procession to the chapel of their patron saint, where they offered a solemn thanksgiving, and afterwards had a painting made representing the conflict with the cuttle, and which was hung in the chapel.

But let Montfort, who was once painfully bitten in the side by an octopus, whose bite, he says, is not poisonous, relate one of his own experiences:

On one occasion a huge mastiff which accompanied me on my explorations drew my attention by his excited barking. When I came to the rocks I found a cuttlefish, whose arms were 3 feet long. He was defending himself against the violent attacks of the dog, an animal of immense size and strength and undaunted courage, which had already once saved my life when attacked by a wolf. The dog ran around the cuttle, vainly attempting to seize the arms, which followed him with singular dexterity and lashed him over the back like whips. I looked on a minute in great astonishment at the dexterity of the cuttle, which seemed full of rage, and showed no desire to retreat, though the water was just behind it. When it saw me it seemed for the first time somewhat intimidated. There was a change in its tactics. The arms struck out less often, and it endeavored to drag itself to the shore. Seeing this, my brave dog seemed encouraged. Watching a chance, he leaped within the arms and fastened his teeth in one, quite near the body.

Instantly four arms were drawn up and twined rigidly about the dog, who struggled vainly to free himself, and, for once losing his courage, uttered piteous howls and cries for help. Meantime the cuttle, whose huge protruding eyes seemed actually to flash fire, and whose body had turned many colors, from dark violet to bright scarlet, was drawing itself with considerable speed toward the water, dragging with little effort the heavy body of my struggling dog. The rough rocky ground helped him to drag the weight along, by giving his arms secure holds.

Already the monster had reached the water side, when I could no longer bear the sight, and rushed to the help of my faithful dog. I seized two of the arms of the cuttle, and, bracing my feet firmly against a solid rock, pulled with all my strength. I succeeded in tearing loose these arms. The animal

struggled, uttered cries of rage which resembled the growl of a fierce watch-dog, and finally attacked me, too, throwing two of its arms about my person. But my brave dog had not been idle. Gathering courage from my advance, he had succeeded in quite tearing off with his strong teeth two of the arms of the cuttle; and with another struggle he was free. Then, with a fury which I never saw equaled, he attacked the disabled monster, which we together soon overpowered.

I determined never again to attack an animal of this kind unarmed, or to venture to close quarters with it.

Beale, an English physician, who made a whaling voyage in 1831–32, described an octopus adventure worth relating.

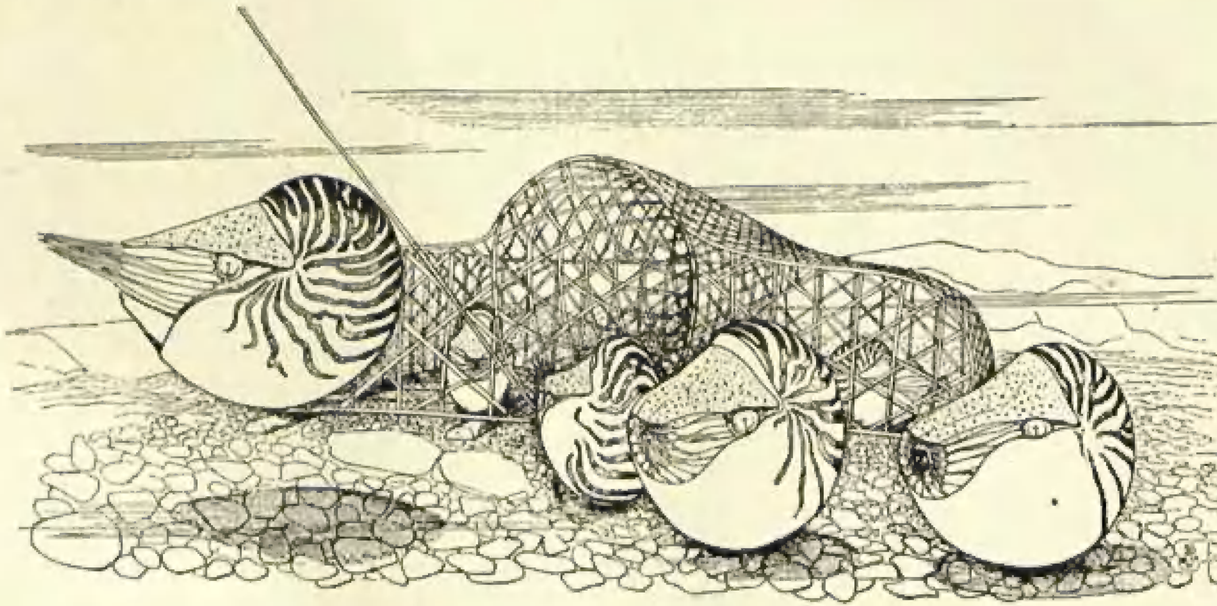
While upon the Bonin Islands, searching for shells upon the rocks which had been left by the receding sea tide, I was much astonished at seeing at my feet a most extraordinary looking animal crawling toward the surf which had only just left it. I had never seen one like it under such circumstances before; it therefore appeared the more remarkable. It was creeping on its eight legs, which, from their soft and flexible nature, bent considerably under the weight of its body, so that it was lifted by the effort of its tentaculae only a small distance from the rocks. It appeared much alarmed at seeing me, and made every effort to escape, while I was not much in the humor to endeavor to capture so ugly a customer, whose appearance excited a feeling of disgust not unmixed with fear. I, however, endeavored to prevent its escape by pressing on one of its legs with my foot; but although I made use of considerable force for that purpose, its strength was so great that it several times quickly liberated its members, in spite of all the efforts I could employ in this way on wet, slippery rocks. I now laid hold of one of the tentacles with my hand and held it firmly, so that the limb appeared as if it would be torn asunder by our united strength. I soon gave it a powerful jerk, wishing to disengage it from the rocks to which it clung so forcibly by its suckers. This it effectually resisted; but the moment after the apparently enraged animal lifted its head, with its large eyes projecting from the middle of its body, and letting go its hold on the rocks suddenly sprang upon my arm, which I had previously bared to my shoulder for the purpose of thrusting into holes in the rocks to discover shells. It clung with its suckers with great power, endeavoring to get its beak, which I could now see between the roots of its arms, in a position to bite. A sensation of horror pervaded my whole frame when I found this monstrous animal had affixed itself so firmly to my arm. Its cold, slimy grasp was extremely sickening; and I immediately called aloud to the captain, who was also searching for shells at some distance, to come to my release from my disgusting assailant. He quickly arrived, and taking me down to the boat, during which time I was employed in keeping the beak away from my hand, quickly released me by destroying my tormentor with the boat knife, when I disengaged it by portions at a time. This animal must have measured across its expanded arms about 4 feet, while its body was not larger than a large clenched hand. It was that species of sepia which is called by whalers "rock squid."

And yet another narrative is taken from Cassell's Natural History:

The following account of a marine diver, attacked by an octopus, exhibits the behavior of these animals toward any being that intrudes upon them in their native element: On 4th November, 1879, Mr. J. Smale, Government diver, was at work at the bottom of the tideway of the River Moune, Melbourne. Having placed a charge of dynamite between two large stones, he came up and exploded it, and on descending again found one of the stones

A SAILING ARGONAUT.

Showing the animal as it does not swim.



NAUTILUS POMPILUS L. SHOWING TRAP USED BY THE FILIPINOS FOR THEIR CAPTURE.

From "Notes on Living Nautilus," by Bashford Dean. American Naturalist, vol. 35, p. 820, 1901.

thrown out, which he sent up, and then hooked on to another, but could not start it, and having descended again, the current being pretty strong at the time, he stretched himself out on the stone, and reaching his right arm down to feel if he could get another small charge under it, not being able to do this in any other position. "My arm," he says, "was scarcely down, however, before I found that it was held by something, and the action of the water was stirring up the loose clay, and therefore I could not see distinctly for a few minutes, but when it did clear away I saw, to my horror, the arm of a large octopus entwined round mine like a boa constrictor, and just then he fixed some of his suckers on the back of my hand, and the pain was intense. I felt as if my hand was being pulled to pieces, and the more I tried to take it away the greater the pain became, and, from past experience, I knew this method would be useless. But what was I to do, lying in this position? I had the greatest difficulty in keeping my feet down, as the air rushed along the interior of my dress and inflated it, and if my feet had got uppermost I should soon have become insensible, held in such a position, and if I had given the signal to be pulled up the brute would have held on and the chances would have been that I should have had a broken arm. I had a hammer down by me but could not reach it to use it on the brute. There was a small iron bar not far from me, and with my feet I dragged this along until I could reach it with my left hand. And now the fight commenced; the more I struck him the tighter he squeezed, until my arm got quite benumbed, but after awhile I found the grip began to relax a little, but he held on until I had almost cut him to pieces, and then he relaxed his hold from the rock and I pulled him up. I can assure you I was completely exhausted, having been in that position for over 20 minutes. I brought the animal up, or rather a part of it. We laid him out and he measured over 8 feet across, and I feel perfectly convinced that this fellow could have held down five or six men. It is only when a person gets a grip from these brutes that one realizes their strength, and it was lucky for me that I was not an amateur, for I can assure you that I had the greatest struggle to get clear of it that I have ever had with any animal under water.

Here is still another yarn by Aldrovandi, who speaks of the possum-playing of the octopus:

An octopus, considered dead, was placed in a kettle and hung over the fire, became revived, and gained sufficient strength to leave the kettle, climb through the chimney, and seat himself upon the roof, where, after considerable hunting, he was discovered.

While Pennant states, on authority of a friend long resident in the East Indies, that—

in those seas, the eight-armed cuttlefish has been found of such size as to measure 12 feet in breadth across the central part, while each arm was 54 feet in length; thus making it extend, from point to point, about 120 feet (pl. 10).

He further states that—

the natives of the Indian Isles, when sailing in their canoes, always take care to be provided with hatchets, in order immediately to cut off the arms of such of these animals as happen to fling them over the sides of the canoe, lest they should pull it under water and sink it.

Quite an excellent picture made by Gustave Doré showing Gilliatt's fight with the devilfish in Victor Hugo's Toilers of the

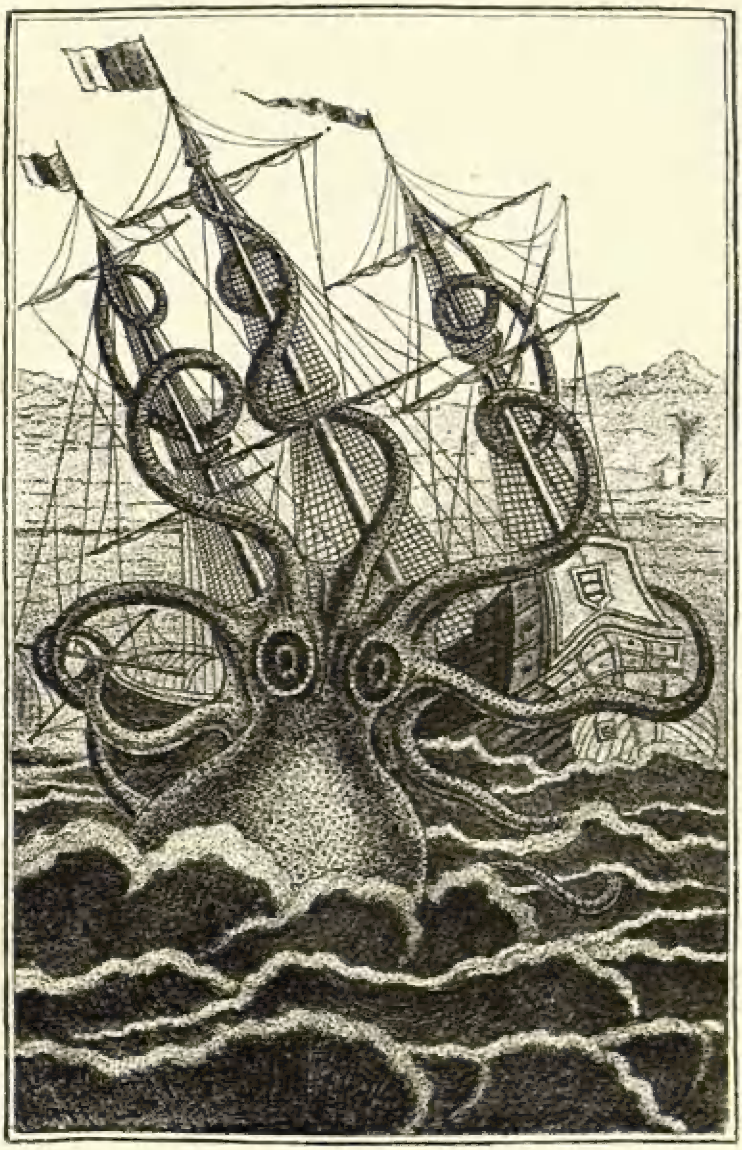
Sea is here reproduced (pl. 11), but we regret greatly that the author's powers of observation were not on a par with his wonderful gift of dramatic diction, for a trifle more knowledge would have raised this chapter from the limbo of silly yarns to a production worthy of Victor Hugo. The following statement, which we quote from the above work, contains not a single atom of truth, although the author attempts to strengthen his case by referring to men of science, from whose works he undoubtedly gleaned some of his rare information:

Fig. 2.—Modern conception of an octopus. From newspaper clipping.

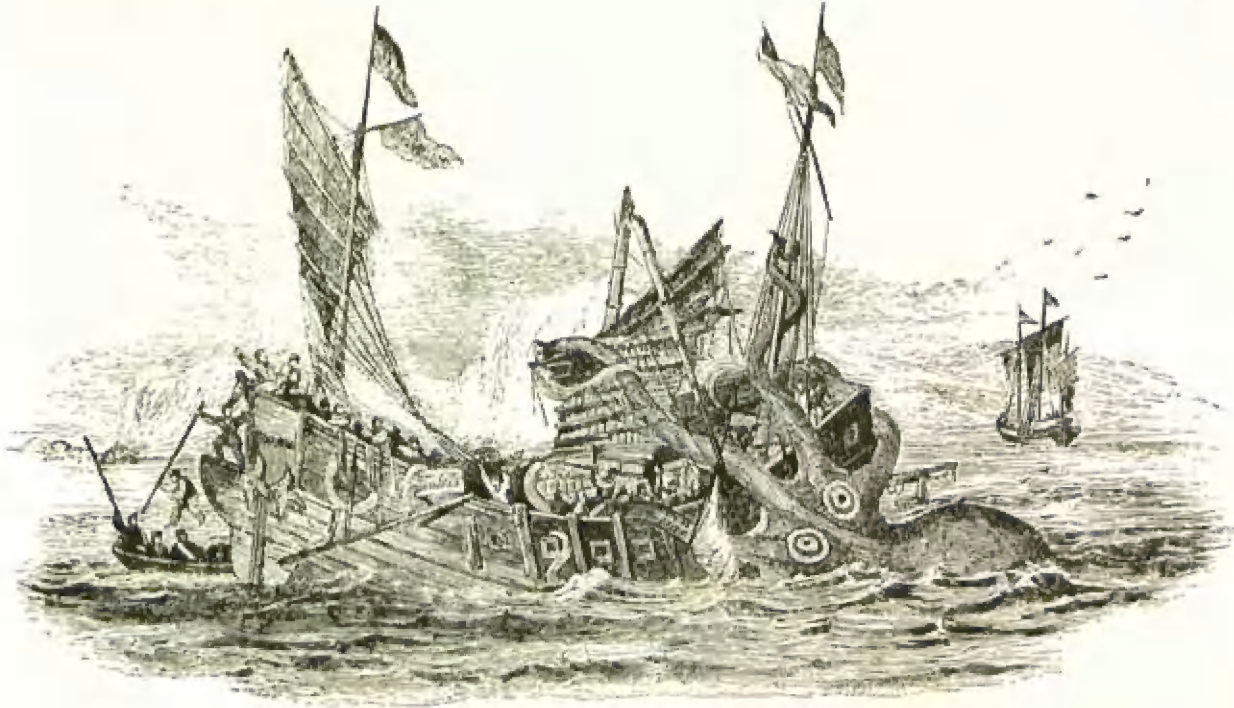
> The muscles swell, the fibers of the body are contorted, the skin cracks under the loathsome oppression, the blood spurts out and mingles horribly with the lymph of the monster, which clings to its victim by innumerable hideous mouths. The hydra incorporates itself with the man, the man becomes one with the hydra. The spectre lies upon you; the tiger can only devour you; the devilfish, horrible, sucks your lifeblood away. He draws you to him, and into himself; while bound down, glued to the ground, powerless, you feel yourself gradually emptied into this horrible pouch, which is the monster.

It would be unfair to leave the Octopoda without calling attention to the efforts of some of the modern story tellers. We select for this purpose a clipping from the San Francisco Chronicle, reproduced in figure 2. This is a marvelous combination of crab and octopus; the artist has terminated not only every one of the eight arms in a pair of pincers, but he has even modified the body into a claw.

An endless number of instances might be quoted from the daily press relating struggles between man and the octopus, not all of which have terminated as favorably as those which we have quoted.



REPRODUCTION OF A PAINTING IN THE CHAPEL OF ST. THOMAS AT ST. MALOS, FRANCE.



AN OLD ILLUSTRATION, SHOWING A SAILING VESSEL ATTACKED BY AN OCTOPUS IN THE INDIAN SEA.

The octopus is carnivorous, and hence must seek his animal prey. He lives chiefly on mollusks and fish, and even Pliny, in the long ago, shows a remarkable knowledge of their habits, for he states:

They feed upon the flesh of shellfish, the shells of which they can easily break in the embrace of their arms; hence it is that their retreat may be easily detected by the pieces of shell which lie before it. * * * In its own domestic matters it manifests considerable intelligence. It carries its prey to its home, and after eating all the flesh, throws out the débris, and then pursues such small fish as may chance to swim toward them. It also changes its color according to the aspect of the place where it is, and more especially when it is alarmed.

The octopus, however, is not always the hunter, but frequently the hunted. Not least among his enemies is man, for since very ancient times he has been considered a choice morsel in many countries. The Greeks and Romans considered them the finest fish in the sea. Pliny tells us that the gourmands of Rome ate every variety of octopus known in the Mediterranean. They were cooked in a pie, the arms being cut off, and the body filled with spices; and the Romans were so careful in their preparation that their cooks used pieces of bamboo for drawing the body, instead of knives of iron, which were supposed to communicate an ill flavor to the delicious morsel. How highly the cuttle was esteemed by the Greeks is evident from a story told of Philoxenus of Syracuse, who, desiring a delicious dinner, caused a polypus of three feet spread to be prepared for the principal dish. He ate it alone, all but the head, and was taken so sick in consequence of his surfeit that a physician was called. On being bluntly told that his case was desperate, and that he had but a few hours to live, Philoxenus called for the head which had been left over from dinner, ate that, and resigned himself to his fate, saying that he left nothing on the earth which seemed to him worthy of regret.

The methods employed in their capture vary with the people pursuing them. Aristotle tells us that the cuttlefish and the octopus may be caught by bait. The octopus, in fact, clings so tightly to the rocks that it can not be pulled off, but remains attached even when the knife has been employed to sever it; and yet, if you apply fleabane to the creature, it drops off at the very smell of it. This procedure is still common on the Mediterranean shores, where either fleabane (*Inula coryza*) or the even handier drug tobacco is used for this purpose.

Simmonds, in his Commercial Products of the Sea, gives the following quotation from Vice Consul Green's report on octopus fishing on the Tunisian coast in modern times:

On the first arrival of the Octopodia in the shallows they keep in masses or shoals, but speedily separate in search of shelter among the rocks near the beach, covered by only 1 or 2 feet of water, and in the stony localities prepared

for them by the fishermen in order to frustrate the depositing of their spawn. Polypi are taken in deep water by means of earthen jars strung together and lowered to the bottom of the sea, where they are allowed to remain for a certain number or hours, and in which the animals introduce themselves. Frequently from 8 to 10 polypi are taken from every jar at each visit of the fishermen. In less deep water earthenware drainpipes are placed side by side for distances frequently exceeding half a mile in length, and in these also they enter and are taken by the fishermen. As they are attracted by white and all smooth and bright substances, the natives deck places in the creeks and hollows in the rocks with white rocks and shells, over which the polypi spread themselves and are caught from four up to eight at a time. But the most successful manner of securing them is pursued by the inhabitants of Karkenah, who form long lanes and labyrinths in the shallows by planting the butt ends of palm branches at short distances from each other, and these constructions extend over spaces of two or more miles. On the ebb of the tide (the fall here is about 10 feet) the Octopodia are found in the pools inside the inclosures and are easily collected by the fishermen, who string them in bunches of 50 each, and from 8 to 10 of these bunches, called "risina," are secured daily during the season by every boat's crew of four men.

The simplest method, probably, is that used by the Filipinos. Well do I recall my first octopus hunt with them in the southern islands. It was a dark night. The good ship *Albatross* lay peacefully at anchor some half mile off a Moro village, whose dim outline was faintly silhouetted against the sky. We had just finished our dinner, returned to the deck to take up submarine light fishing, when we noticed a torchlight procession proceeding from the village down the sand spit that fringed a reef. The orderliness of the procedure soon changed to what one at our distance might have considered some wild ceremonial dance.

Our curiosity being thoroughly aroused, we lowered a boat and soon joined the party of men and boys, who were clad in the conventional G-string costume, each provided with a torch varying from about 4 to 6 inches in diameter and probably 10 to 12 feet in length, made of slender segments of dried, split bamboo, carried on the left shoulder, held by the left hand, and lighted in front. The right hand was reserved for the ever-present bolo or a spear. The light of these torches would show through the shallow water and thus reveal the luckless devil fish, which seemed to have forsaken the secure caverns of the reef and to have gone a-hunting on the shallow flats within. They are curious creatures, and their humped-up attitude and large eyes render them rather mirth provoking at such times. But there is little time given to contemplating, for a native bolo or spear brings him in and he is promptly strung on a rattan string, where he may continue to squirm with his fellow captives until dead.

We secured enough specimens that night to enable us to spare some to the cook, for Ming assured us that they were "vely good." So they were—rather, I should say it was, for I chewed a single

GUSTAVE DORÉ'S ILLUSTRATION OF GILLIATT'S FIGHT WITH THE OCTOPUS IN VICTOR HUGO'S "TOILERS OF THE SEA."

AN OCTOPUS FEEDING ON FISH.

By permission, from "Denizens of the Deep," by Frank T. Bullen. Fleming H. Revell Co., publishers.

tentacle the greater part of the following forenoon and relinquished it only, and that with regret, when my jaws, aching from overexertion, refused to operate more.

On the island of Guam we found an entirely different method in use. Here we watched the natives fishing for the octopus on the inside of the slender reef that stretched from Capra Island toward the steamer entrance to the beautiful Piti Bay and Harbor. The natives here take a specimen of a large, repulsive-looking Holothurian and tie it to a line with a sinker. This is lowered among the crevices of the reef. If it finds a cavity with an octopus the animal at once leaves the premises and is then easily speared by the man in the bow of the canoe. There is evidently something about the Holothurian that is so intensely distasteful to the octupus that he at once forsakes his lair.

It is quite a picture to see these fishermen as they work in the very teeth of the pounding surf with a craft so frail that one constantly wonders how they manage to keep it from being dashed to pieces.

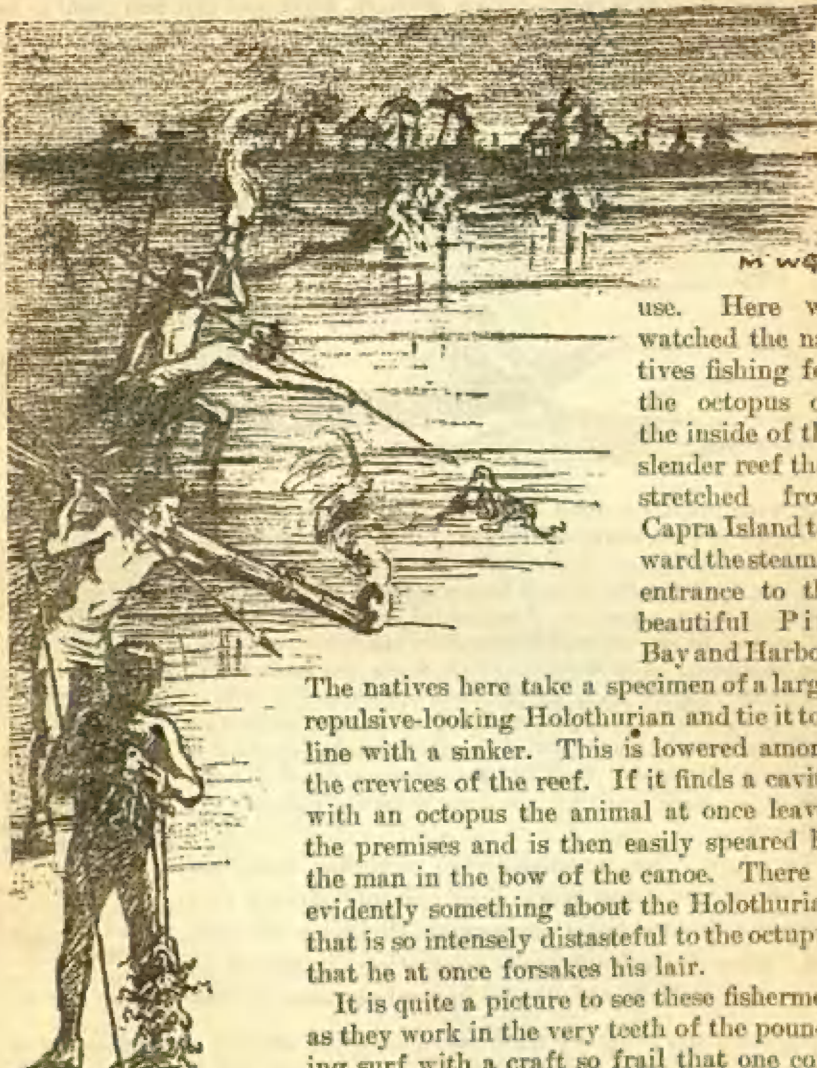


Fig. 3.—Torchlight octopus hunt in the Philippines.

The following is a quotation taken from an article by Dr. H. M. Smith on "Japan, the Paramount Fishing Nation,"[1] which shows how the Japanese fishermen catch these animals:

The octopus or devilfish is abundant and is an important food product in Japan, although my personal opinion is that it does not appeal strongly to the

[1] Transactions of the American Fisheries Society, July, 1904, p. 119.

American palate. The octopus is caught in various ways, one of the most interesting of which is by the use of earthenware pots, which are lowered to the bottom by means of cords; they are entered by the octopuses, which, having insinuated themselves, are reluctant to withdraw, so that the pots may be pulled to the surface before the animals try to escape. I bring up this fishery in order to refer to a very ingenious corollary, which was first mentioned to me by a professor in the imperial university and later verified by myself. More

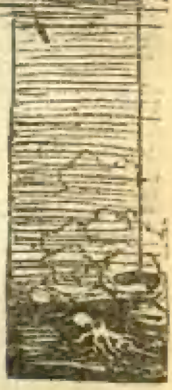
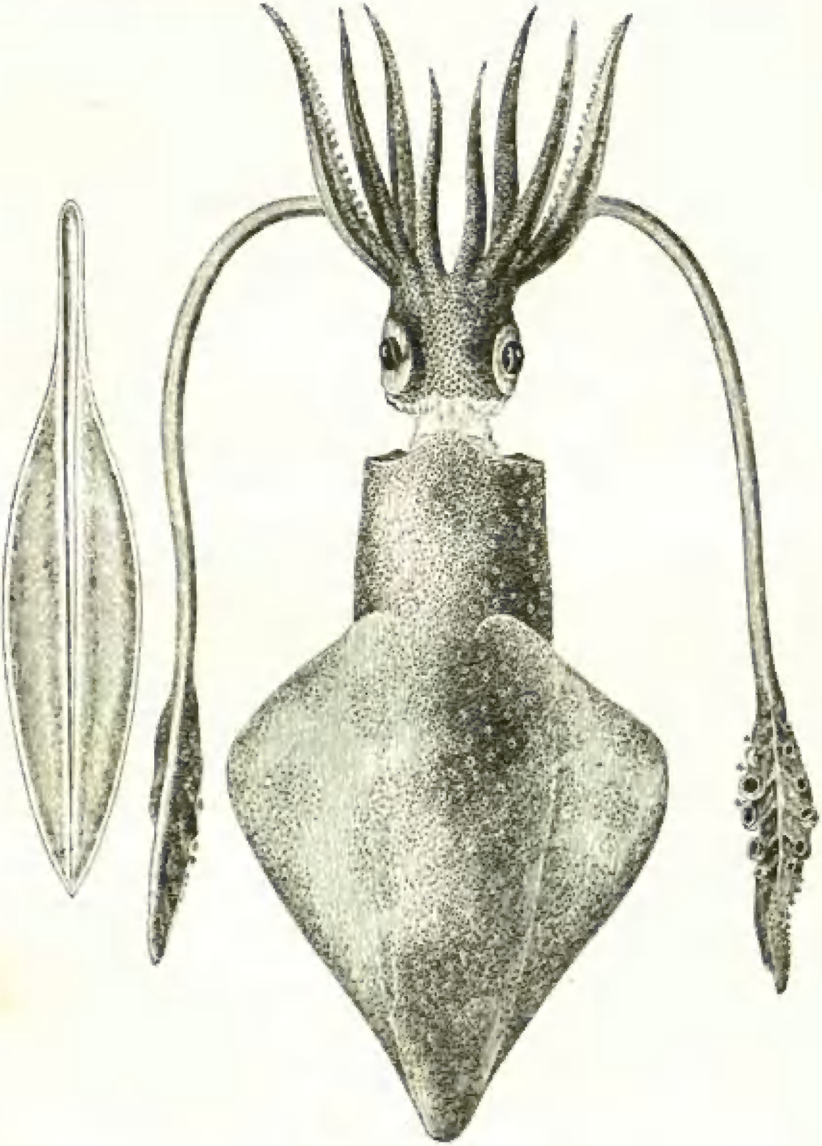


FIG. 4.—Fishing for octopus on the reef at Guam.

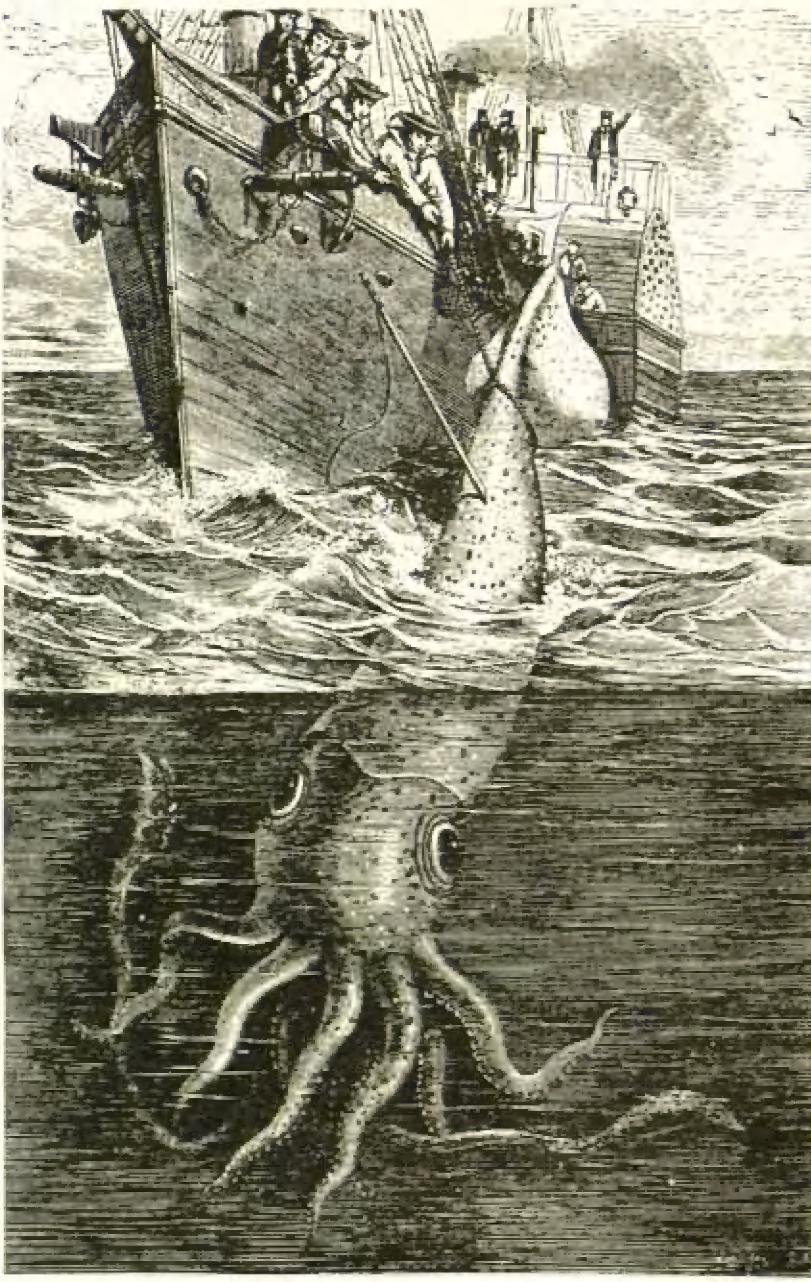
than a century ago a vessel laden with a very valuable cargo of porcelains from Korea destined for the imperial household was wrecked in the Inland Sea; the captain and other officers did what seems to have been a favorite amusement of the olden days; namely, they committed suicide just before the vessel sank in deep water. Recently the fishermen have been recovering pieces of this pottery, which now has an appreciated value, by tying strings to octopuses and lowering them in the vicinity of the wreck. The animals enter the vessels and retain their hold of them while being drawn to the surface. Several pieces of this porcelain which I saw were gems, seeming but little the worse for their prolonged submergence.

To show how extensive the octopus fisheries are we again quote from Vice Consul Green's report in Simmonds's Commercial Products of the Sea, who furnishes some interesting particulars as to the fishing and trade in cephalopods in the Tunis waters:

Octopodia and polypi are the trade names under which these cephalopods are known in the Levant and Greek markets, where they are solely imported for consumption during Lent, the Orthodox Church not including them in the prohibition against the use of flesh in seasons of religious abstinence. In a good season the several villages on the island of Karkenah supply about 3,000 hundredweight, and the Jubah waters a third part of this quantity. In an average year the yield will be under 2,000 hundredweight, and in one of scarcity 1,000 hundredweight. On the shores from the village of Lucsa to that of Chenles, in the Gulf of Khabs, the natives collect from 4 to 5 hundredweight of cuttlefish a day during the season, but this supply generally serves for the consumption of



A CUTTLEFISH (LOLIGO VULGARIS L.).



AN ENCOUNTER WITH A GIANT SQUID.

the regency. The remaining coast and islands may be calculated to furnish a minimum of 650 to 700 hundredweight of dried molluscs.

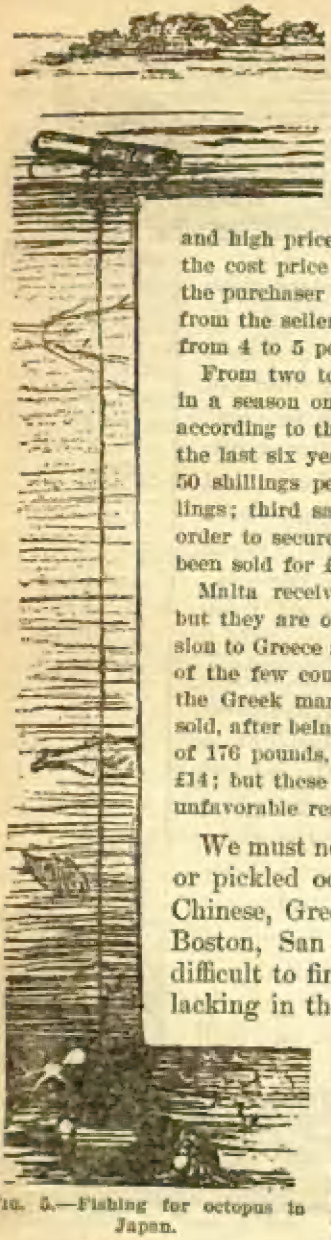


FIG. 5.—Fishing for octopus in Japan.

The Tunisian Government claims a third of all the polypi fished upon its coast. The selling price varies considerably according to the size, supply, and demand, but at Sfax a pair of them may cost, as circumstances rule, from 6d. to 1s. 3d.; however, the preparatory maceration, by beating on a stone slab or rock, required before drying entails a small additional expense and brings the extremes of low and high prices to 25 or 50 shillings per hundredweight. To the cost price must be added an export duty of 5s. 1d. and the purchaser ought to be careful to receive his merchandise from the seller during dry weather, as a damp day will add from 4 to 5 per cent to the weight of every hundredweight.

From two to three public sales of dried polypi take place in a season on the island of Karkenah; these are regulated according to the abundance of the fish. The average price of the last six years has been: During the first sale, from 45 to 50 shillings per hundredweight; second sale, 35 to 45 shillings; third sale, 25 to 30 shillings. A few first parcels, in order to secure an early market, have, however, occasionally been sold for £5 the hundredweight.

Malta receives the largest share of the Tunisian polypi, but they are only sent to that island for ultimate transmission to Greece and other parts of the Levant. Portugal is one of the few countries that competes with Tunis in supplying the Greek markets with polypi. In Greece they are either sold, after being pickled, at from £12 16s. to £15 9s. the cantar of 176 pounds, or, in their original dried state, from £12 to £14; but these prices fluctuate according to the favorable or unfavorable results of the season's fishing.

We must not forget that while we see little of dried or pickled octopi in our own country except in the Chinese, Greek, and Italian markets of New York, Boston, San Francisco, and Chicago, it would be difficult to find a food dealer in the oriental markets lacking in these choice dainties.

So much, then, for the octopus, the animal that in modern times has become the emblem of selfishness and iniquity.

Let us next turn to the decapods, our squids and cuttlefishes, for it is here that we find the most wonderful members of the group. Inch for inch, the squids will compete in swimming power with any other creature that lives in the sea.

Well do I recall the rude awakening to which I was subjected when I tried to capture some slender Loligopsoid squids in the southern

Philippines. I had always been told that squids were old-fashioned, antiquated relics of the past, whose very method of backward progression marked them as unfit competitors with other marine animals.

It was on board the *Albatross* in the harbor of Jolo on a dark night, with the sea as smooth as glass. We were fishing with the submarine light, a mere 16-candlepower electric bulb inclosed in a glass globe connected to a water-tight cable. It should be stated that the sea about Jolo Harbor was found to be one of the richest plankton-bearing pieces of water that it has been my good fortune to visit; and where you have an abundance of microscopic life, there, too, will you find the larger forms that subsist upon it. A swish or two of the light and a raising and lowering of it at once attracted a cloud of minute forms, then larger elements came, in part attracted by the light and in part by the food. The protozoans accumulating about the globe were soon followed by worms and crustaceans, whose tangential course would soon have carried them beyond our light were it not that the fascination curves it more and more and apparently renders the animal unable to escape from the charm that draws, and bends its path to spin about the globe. Thus we soon found millions of creatures drawn into a spinning vortex about our light—the "wheel of life," as some one has aptly termed it. But new members were soon added; small fish of various kinds, a school of sardines dashing madly after the small crustaceans and worms, and still larger and larger fish at greater distances from the light, always preying upon the lesser circle within; now and then even the shadowy outline of a large shark injected itself into the distant reaches of our lamp. It was a mad dance, this whirling, circling host of creatures. Soon a new element entered; living

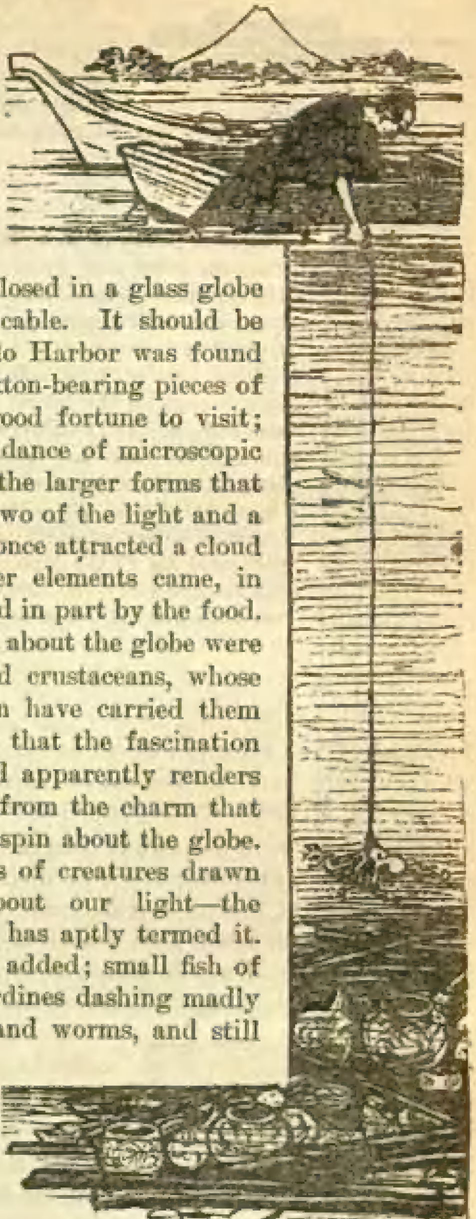


FIG. 6.—Fishing with octopus in Japan.

arrows, a school of Loligopsis shooting across our lighted field, apparently not so much attracted by the light as by the feast before them. They were wonderful creatures, unlike anything else; they shot forward or back like a shuttle, with lightning rapidity. Not only that, but they were able to divert their course into any direction with equal speed. Shooting forward, their tentacles would seize a small fish, and instantly they would come to a full stop, only to dart backward like a flash at the least sign of danger. Kill, kill, kill; they were bloodthirsty pirates. A bite in the neck, and the fish was done for; but the sport continued, and, likely as not, the fish would be dropped and another seized and dispatched. Never before nor since have I seen anything that appeared to me more beautifully equipped for an aquatic existence than these squids. Frequently—yes, very frequently—their impetuous darts would carry them away above the surface of the sea; flying squids, when the pumping of their siphons produced a popping sound.

I tried to jig some of them, having heard that the Newfoundland fishermen employ a sinker with a series of hooks attached to it, which they bob up and down in the water, thereby attracting the squids and hooking them. But our Sulu squids refused to be hooked. They would dash up to the contrivance, follow it at a safe distance, but disdained to be caught. They would even snatch from the hooks the small fish used as a bait, and make good their escape. Even the expert jiggers aboard failed to catch them. The bright idea to float a pocket net from the beam and have them enmesh themselves in it occurred to someone. This was tried, and we found that our squids possessed an intelligence equal to their lightning movements. Did they enmesh themselves? Oh, no; not one of the thousand or more that composed the school, but they seemed to enjoy shooting through a hole in our seine and it was a comical as well as wonderful sight to see them dart through this opening not more than 18 inches in diameter, like arrows fired from a rapid-fire machine gun. Now and then the whole school would come near the surface and pause, then again it would sink to a depth beyond our range of vision. Then they would line up on the far side of our net, sink below it, and shoot up on our side, to make an assault upon the small fish fry which attempted to escape by breaking from the water.

We finally did capture some by carefully watching the speedy flight of an individual near the surface and quickly casting our dip net ahead of him. But three nights' efforts of a half a dozen fishermen yielded only a couple of dozen specimens.

These were wonderful nights in the Sulu Sea! Turn off the electric current, and where a moment before you saw a mass of circling life, you now have a glowing whirlpool, each spark an atom of life,

while bright phosphorescent streaks mark the movement of the larger forms, themselves luminous or rendered so by exciting their smaller neighbors to flash as they come in contact.

An endless array of species has been made known by our scientists—species large and small, slender and stout, long and short; species with wondrous eyes and blind species, many of the deep-sea forms bearing complex luminous organs, and all of them possessing wonderfully developed chromatophores which can be contracted or enlarged at the animal's will. The contraction may reduce them to a mere dot, or they may be expanded to 20 times that diameter. The changes in the contraction of thousands of these minute pigment cells, some of which are rosin colored, others yellow, blue-green, or brown, produce the flashes and changes of color that have gained the name of "chameleons of the sea" for our squids.

The literature of the past abounds in sea-serpent myths, which in a large measure are traceable to giant squids. For these are the only known animal whose arms can, without distortion, be made to assume a serpentine form. This is clearly shown by our sketch which is proportioned, excepting partly the thickness of the tentacular arms, which has been slightly increased, after measurements of an actual specimen. The expanded end of these long arms, studded with suckers, might easily be mistaken for the bearded or maned head, usually assigned to the serpent. There would be enough basis in a short view of such a vision at long range to enable the untrained mind to supply more than enough detail from the imagination to create a kraken, kraxen, krabben, korven, ankertrold, soe-horven, a haf-gua, soe ormen, horven, aale-tust, or sea serpent. Another thing very suggestive in support of this explanation is the fact that the known distribution of the giant squids is coextensive with the regions from which the above-named beasts have been reported. It is also interesting to note that the size of these mystic animals has decreased with increased ocean travel and general education. While sea serpents are annually reported in sea-serpent season, no one except the fearless sailors of old who braved the dangers of the deep in their small vessels, have been favored with such visions as one finds related by the Rt. Rev. Erich Pontoppidan, Bishop of Bergen in Norway, and member of the Royal Academy of Sciences at Copenhagen, in his Natural History of Norway. We quote from a translation published in London in 1755 (pp. 199–200):

Another drawing also, which appears more distinct with regard to the form of this creature, was taken from the reverend Mr. Egede's journal of the Greenland mission, where the account stands thus in page 6: "On the 6th of July, 1734, there appeared a very large and frightful sea monster, which raised itself up so high out of the water that its head reached above our maintop. It has a

sharp snout, and spouted water like a whale, and very broad paws. The body seemed to be covered with scales, and the skin was uneven and wrinkled, and the lower part was formed like a snake.

After some time the creature plunged backward into the water and then turned its tail up above the surface a whole ship-length from the head. The following evening we had very bad weather. So far Mr. Egede. The drawing annexed gives me the greatest reason to conclude (what by other accounts I have thought probable) that there are sea snakes, like other fish, of different sorts. That which Mr. Egede saw, and probably all those who sailed with him, had under its body two flaps, or perhaps two broad fins; the head was longer and the body thicker and much shorter than those sea snakes of which I have had the most consistent accounts. Though one can not have an opportunity of taking the exact dimensions of this creature, yet all that have seen it are unanimous in affirming, as far as they can judge at a distance, it appears to be of the length of a cable, i. e., 100 fathoms, or 600 English feet; that it lies on the surface of the water (when it is very calm) in many folds, and that there are, in a line with the head, some small parts of the back to be seen above

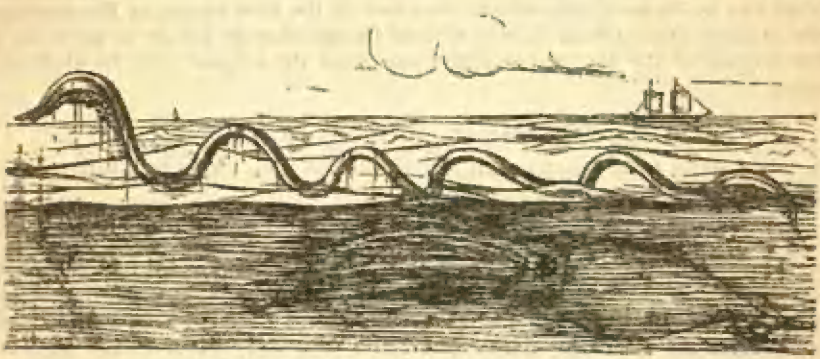


Fig. 7.—Giant squid in rôle of sea serpent.

the surface of the water when it moves or bends. These at a distance appear like so many casks or hogsheads floating in a line, with a considerable distance between each of them. Mr. Tuchsen, of Herroe, whom I mentioned above, is the only person, of the many correspondents I have, that informs me he has observed the difference between the body and the tail of this creature as to thickness. It appears that this creature does not, like the eel or land snake, taper gradually to a point, but the body, which looks to be as big as two hogsheads, grows remarkably small at once just where the tail begins. The head in all the kinds has a high and broad forehead, but in some a pointed snout, though in others that is flat, like that of a cow or a horse, with large nostrils, and several stiff hairs standing out on each side like whiskers.

It is supposed that the sea snakes have a very quick smell, which we may conclude from this, that they are observed to fly from the smell of castor. Upon this account, those that go out on Stor-Eggen to fish in the summer, always provide themselves with these animals. They add, that the eyes of this creature are very large, and of a blue color, and look like a couple of bright pewter plates. The whole animal is of a dark-brown color, but it is speckled and variegated with light streakes or spots, that shine like tortoise shell. It is of a darker hue about the eyes and mouth than elsewhere, and appears in that part a good deal like those horses, which we call moors heads.

I do not find by any of my correspondents, that they spout the water out of their nostrils like the whale, only in that one instance related by Mr. Egede, as mentioned above; but when it approaches, it puts the water in great agitation, and makes it run like the current at a mill. Those on our coast differ likewise from the Greenland sea snakes, with regard to the skin, which is as smooth as glass, and has not the least wrinkle, but about the neck, where there is a kind of a mane, which looks like a parcel of seaweeds hanging down to the water.

The observer undoubtedly mistook the tail of a giant squid for the head of the serpent and the flukes for the limbs.

We quote again (pp. 202–203):

One of the aforesaid North traders, who says that he has been near enough to some of these sea snakes (alive) to feel their smooth skin, informs me, that sometimes they will raise up their frightful heads, and snap a man out of a boat, without hurting the rest; but I will not affirm this for a truth, because it is not certain that they are a fish of prey. Yet this, and their enmity to mankind, can be no more determined, than that of the land snake, by the words of the prophet Amos (chap. ix, v.3): "And though they be hid from my sight in the bottom of the sea, thence will I command the serpent, and he shall bite them."

And again (p. 207) Magnus, in his Histor. Septentrion. Lib. 21. c. 24, speaks of a Norwegian sea snake 80 feet long, but not thicker than a child's arm. He says:

This creature, was put to such pain by the crabs fastening on it, that it writhed itself into a hundred shapes. I have never heard of this sort from any other person, and should hardly believe the good Olaus, if he did not say that he affirmed this from his own experience. * * * The disproportion betwixt the thickness of a child's arm, and a length of 80 feet, makes me think there must be an error of the press in the place, for xl. perhaps should be xi. ells, or 22 feet; a more proportionable length, for the thickness.

And yet good Olaus's observation may not have been so very wrong, in fact much nearer the truth than the above listed yarns, in all probability it represented the tentacular arms of a giant squid.

To show the keenness of observation of early seamen, we quote the following from the same source (pp. 211–213):

Our fishermen unanimously affirm, and without the least variation in their accounts, that when they row out several miles to sea, particularly in the hot summer days, and by their situation (which they know by taking a view of certain points of land) expect to find 80 or 100 fathoms water, it often happens that they do not find above 20 or 30, and sometimes less. At these places they generally find the greatest plenty of fish, especially cod and ling. Their lines, they say, are no sooner out than they may draw them up with the hooks all full of fish; by this they judge that the kraken is at the bottom. They say this creature causes those unnatural shallows mentioned above, and prevents their sounding. These the fishermen are always glad to find, looking upon them as a means of their taking abundance of fish. There are sometimes 20 boats or more got together and throwing out their lines at a moderate distance from each other; and the only thing they then have to observe is whether the depth continues the same, which they know by their lines, or

whether it grows shallower by their seeming to have less water. If this last be the case, they find that the kraken is raising himself nearer the surface, and then it is not time for them to stay any longer. They immediately leave off fishing, take to their oars, and get away as fast as they can. When they have reached the usual depth of the place and find themselves out of danger, they lie upon their oars, and in a few minutes after they see this enormous monster come up to the surface of the water. He there shows himself sufficiently, though his whole body does not appear, which, in all likelihood, no human eye ever beheld, excepting the young of this species, which shall afterwards be spoken of. Its back or upper part, which seems to be in appearance about an English mile and a half in circumference—some say more, but I choose the least for greater certainty—looks at first like a number of small islands surrounded with something that floats and fluctuates like seaweeds. Here and there a larger rising is observed like sand banks, on which various kinds of small fishes are seen continually leaping about till they roll off into the water from the sides of it. At last several bright points of horns appear, which grow thicker and thicker the higher they rise above the surface of the water, and sometimes they stand up as high and as large as the masts of middle-sized vessels.

It seems these are the creature's arms, and, it is said, if they were to lay hold of the largest man-of-war they would pull it down to the bottom. After this monster has been on the surface of the water a short time it begins slowly to sink again, and then the danger is as great as before, because the motion of his sinking causes such a swell in the sea and such an eddy or whirlpool that it draws everything down with it, like the current of the river Male, which has been described in its proper place. As this enormous sea animal, in all probability, may be reckoned of the Polype, or of the starfish kind, as shall hereafter be more fully proved, it seems that the parts which are seen rising at its pleasure, and are called arms, are properly the tentacula, or feeling instruments, called horns as well as arms. With these they move themselves and likewise gather in their food.

Besides these, for this last purpose the great Creator has also given this creature a strong and peculiar scent, which it can emit at certain times, and by means of which it beguiles and draws other fish to come in heaps about it. This animal has another strange property, known by the experience of a great many old fishermen. They observe that for some months the kraken, or krabben, is continually eating and in other months he always voids his excrements. During this evacuation the surface of the water is colored with the excrement and appears quite thick and turbid. This muddiness is said to be so very agreeable to the smell or taste of other fishes, or to both, that they gather together from all parts to it and keep for that purpose directly over the kraken. He then opens his arms, or horns, seizes and swallows his welcome guests, and converts them, after the due time, by digestion, into a bait for other fish of the same kind. I relate what is affirmed by many, but I can not give too certain assurances of this particular as I can of the existence of this surprising creature, though I do not find anything in it absolutely contrary to nature. As we can hardly expect an opportunity to examine this enormous sea animal alive, I am the more concerned that nobody embraced that opportunity which, according to the following account, once did and perhaps never more may offer of seeing entire when dead. The Rev. Mr. Friis, consistorial assessor, minister of Bodoen, in Nordland, and vicar of the college for promoting Christian knowledge, gave me at the latter end of last year, when he was at Bergen, this relation, which I deliver again on his credit.

In the year 1680 a krake (perhaps a young and careless one) came into the water that runs between the rocks and cliffs in the parish of Alstahoug, though the general custom of that creature is to keep always several leagues from land, and therefore of course they must die there. It happened that its extended long arms, or antennae, which this creature seems to use like the snail—in turning about—caught hold of some trees standing near the water, which might easily have been torn up by the roots; but besides this, as it was found afterwards, he entangled himself in some openings or clefts in the rock, and therein stuck so fast, and hung so unfortunately, that he could not work himself out, but perished and putrified on the spot. The carcass, which was a long while decaying and filled a great part of that narrow channel, made it almost impassable by its intolerable stench.

Let us now turn from these distorted and fanciful images to the animals that are responsible for them. Prof. A. E. Verrill, in his

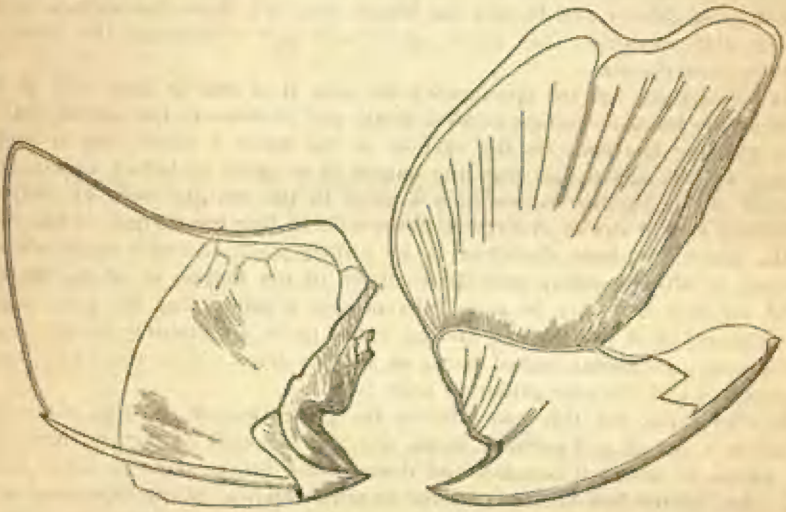
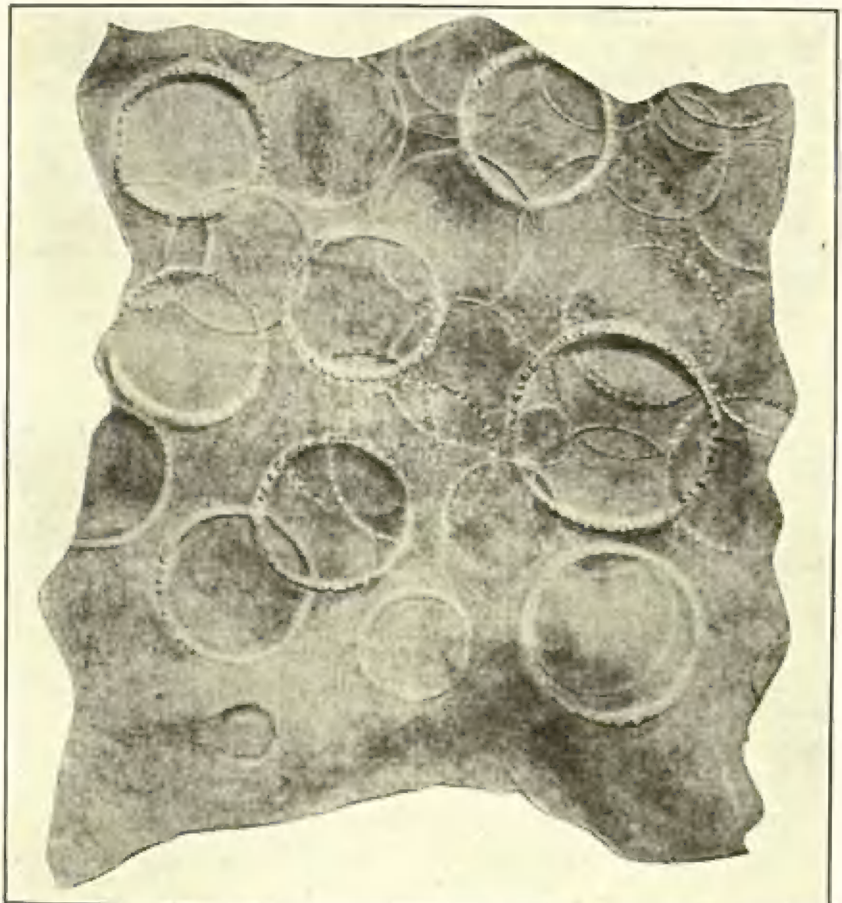


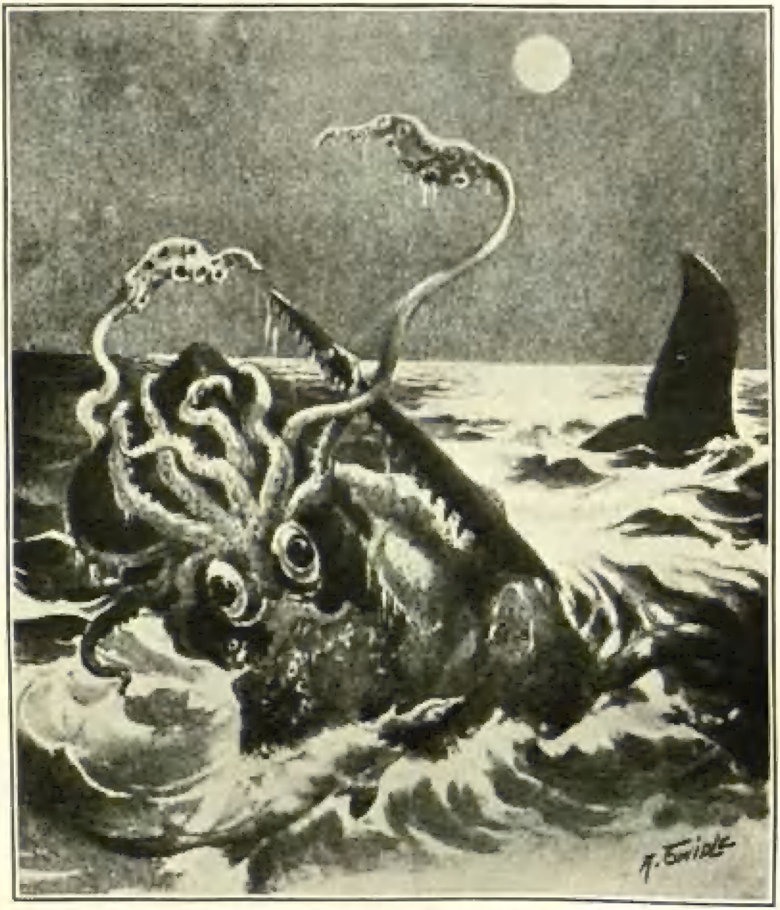
FIG. 8.—Jaws of the giant squid. Half natural size.

report on the cephalopods of the northeastern coast of America, published in the annual report of the Commissioner of Fish and Fisheries for 1879, tells us many interesting things about the American members of the group. Among other things he presents a table on page 22 which gives measurements of the various giant squids that he had examined to date. The largest of these had a total length of 55 feet. The length of the tentacular arms of this specimen are cited as 35 feet, while the length of the body from tip of tail to the base of the arms is given as 20 feet. The greatest length of tentacular arms mentioned in the table is 37 and the greatest circumference of the body as 12 feet. The diameter of the largest sucker is given as about 2.25 inches, and the breadth of the eye opening is 7 by 9 inches.



A PIECE OF SPERM WHALE SKIN RELATING A BATTLE WITH A GIANT SQUID, IN SUCKER SCAR SCRIPT.

By permission, from "The Depths of the Ocean," by Murray and Hjort. The Macmillan Co.



A FIGHT BETWEEN A SPERM WHALE AND A GIANT SQUID.

By permission, from "The Cruise of the Cachalot," by Frank T. Bullen. D. Appleton & Co.

In another place he states:

A specimen was found alive in shallow water at Coombs Cove and captured. Concerning this one I have seen only newspaper accounts. It is stated that its body measured 10 feet in length and was "nearly as large around as a hogshead" (10 to 12 feet); its two long arms (of which only one remained) were 42 feet in length and "as large as a man's wrist"; its short arms were 6 feet in length but about 9 inches in diameter, "very stout and strong"; the suckers had a serrated edge.

The tentacular arms of this specimen would have had a spread of 84 feet. But I have somewhere seen measurements cited of a specimen that carried the extension beyond the 100-foot mark. A splendid basis for sea-serpent yarns. We again quote from Dr. Verrill:

I have been informed by many other fishermen that these "big squids," as they call them, are occasionally taken on the Grand Banks and used for bait. Others state that they have seen them in that region without being able to capture them. Nearly all the specimens hitherto taken appear to have been more or less disabled when first observed; otherwise they probably would not appear at the surface in the daytime. From the fact that they have mostly come ashore in the night I infer that they inhabit chiefly the very deep and cold fiords of Newfoundland and come up to the surface only in the night.

FIG. 9.—Suckers of the giant squid. Half natural size. 1. From long arm. 2. From short arm.

That they may at times be a danger to man is shown by the following statement which we quote from Dr. Verrill's paper:

The following extract is from a letter written by the Rev. M. Harvey to Dr. J. W. Dawson, and published in the Montreal Gazette, February 26, 1874: "Two fishermen were out in a small punt on October 26, 1873, off Portugal Cove, Conception Bay, about 9 miles from Saint John's. Observing some object floating on the water at a short distance, they rowed toward it, supposing it to be a large sail or the débris of a wreck. On reaching it one of the men struck it with his gaff, when immediately it showed signs of life, reared a parrotlike beak, which they declare was 'as big as a 6-gallon keg,' with which it struck the bottom of the boat violently. It then shot out from about its head two huge livid arms and began to twine them around the boat. One of the men seized a small ax and severed both arms as they lay over the gunwale of the boat; whereupon the fish moved off and ejected an immense quantity of inky fluid, which darkened the water for two or three hundred yards. The men saw it for a short time afterwards, and observed its tail in the air, which they declare was 10 feet across. They estimate the body to have been 60 feet in length, 5 feet in diameter, of the same shape and color as the common squid, and they observed that it moved in the same way as the squid, both backward and forward.

"One of the arms which they brought ashore was unfortunately destroyed, as they were ignorant of its importance; but the clergyman of the village as-

sures me it was 10 inches in diameter and 6 feet in length. The other arm was brought to Saint John's, but not before 6 feet of it were destroyed. Fortunately, I heard of it and took measures to have it preserved. Mr. Murray, of the geological survey, and I afterwards examined it carefully, had it photographed, and immersed in alcohol; it is now in our museum. It measured 19 feet, is of a pale, pink color, entirely cartilaginous, tough, and pliant as leather, and very strong."

In a letter dated November 27, 1877, Mr. Harvey gives an account of another specimen, which was stranded on the shore at Lance Cove, Smiths Sound, Trinity Bay, about 20 miles farther up the bay than the locality of the Catalina Bay specimen (No. 14). He received his information from Mr. John Duffet, a resident of the locality, who was one of the persons who found and measured it. His account is as follows: "On November 21, 1877, early in the morning, a 'big squid' was seen on the beach, at Lance Cove, still alive and struggling desperately to escape. It had been borne in by a 'spring tide' and a high inshore wind. In its struggles to get off it ploughed up a trench or furrow about 30 feet long and of considerable depth by the stream of water that it ejected with great force from its siphon. When the tide receded it died. Mr. Duffet measured it carefully, and found that the body was nearly 11 feet long (probably including the head); the tentacular arms, 33 feet long. He did not measure the short arms, but estimated them at 13 feet, and that they were much thicker than a man's thigh at their bases. The people cut the body open and it was left on the beach. It is an out-of-the-way place, and no one knew that it was of any value. Otherwise, it could easily have been brought to St. John's, with only the eyes destroyed and the body opened." It was subsequently carried off by the tide, and no portion was secured.

From Capt. J. W. Collins, of the United States Fish Commission, I learn that in October, 1875, an unusual number of giant squids were found floating at the surface on the Grand Banks, but mostly entirely dead and more or less mutilated by birds and fishes. In very few cases they were not quite dead, but entirely disabled. These were seen chiefly between north latitude 44° and 44° 30′, and between west longitude 49° 30′ and 49° 50′. He believes that between 25 and 30 specimens were secured by the fleet from Gloucester, Mass., and that as many more were probably obtained by the vessels from other places. They were cut up and used as bait for codfish. For this use they are of considerable value to the fishermen. Capt. Collins was at that time in command of the schooner *Howard*, which secured five of these giant squids. These were mostly from 10 to 15 feet long, not including the arms, and averaged about 18 inches in diameter. The arms were almost always mutilated. The portion that was left was usually 3 to 4 feet long, and at the base about as large as a man's thigh.

One specimen, when cut up, was packed into a large hogshead-tub, having a capacity of about 75 gallons, which it filled. This tub was known to hold 700 pounds of codfish. The gravity of the Architeuthis is probably about the same as that of the fish. This would indicate more nearly the actual weight of one of these creatures than any of the mere estimates that have been made, which are usually much too great. Allowing for the parts of the arms that had been destroyed this specimen would, probably, have weighed nearly 1,000 pounds.

Among the numerous other vessels that were fortunate in securing this kind of bait Capt. Collins mentions the following:

The schooner *Sarah P. Ayer*, Capt. Oakly, took one or two. The *E. R. Nickerson*, Capt. McDonald, secured one that had its arms and was not entirely dead, so that it was harpooned. Its tentacular arms were 36 feet long.

The schooner *Tragabigzanda*, Capt. Mallory, secured three in one afternoon. These were 8 to 12 feet long, not including the arms.

These statements are confirmed by other fishermen, some of whom state that the "big squids" were also common during the same season at the "Flemish Cap," a bank situated some distance northeast from the Grand Banks.

The cause of so great a mortality among these great Cephalopods can only be conjectured. It may have been due to some disease epidemic among them, or to an unusual prevalence of deadly parasites or other enemies. It is worth while, however, to recall the fact that these were observed at about the same time, in autumn, when most of the specimens have been found cast ashore in Newfoundland in different years. This time may, perhaps, be just subsequent to their season for reproduction, when they would be so much weakened as to be more easily overpowered by parasites, disease, or other unfavorable conditions.

Aside from man the sperm whale is undoubtedly the greatest enemy possessed by these monstrous animals, for it is well known that parts of them are usually found in the stomach or are vomited by the sperm whale when the animal is captured by whalers. We quote from The Depths of the Ocean, by Sir John Murray and Dr. Johan Hjort (pp. 651–652):

On the 15th of August the *Michael Sars* arrived in Mofjord on the east coast of Iceland, and visited the local whaling station. On the shore were two freshly caught whales, one a north-caper, the other a cachalot. Inspecting the cachalot I saw around its enormous jaws several long parallel stripes consisting, as closer scrutiny revealed, of great numbers of circular scars or wounds about 27 mm. in diameter. It occurred to me that these scars must have been left by the suckers of a giant squid, and following up this idea I found in the whale's mouth a piece of a squid tentacle 17 cm. in maximum diameter. In the stomach of the whale many squid-beaks of various sizes were found, the largest measuring 9 cm. in length, besides some fish bones, and the men who had shot the whale told me that in its death flurry it disgorged the arm of a squid 6 meters long.

Our illustration (pl. 15) shows the sucker scars in the skin.

An encounter between a sperm whale and giant squid is described in Frank T. Bullen's book on The Cruise of the Cachalot, from which we quote (pp. 143–144).

At about 11 p. m. I was leaning over the lee rail, gazing steadily at the bright surface of the sea, where the intense radiance of the tropical moon made a broad path like a pavement of burnished silver. Eyes that saw not, mind only confusedly conscious of my surroundings, were mine; but suddenly I started to my feet with an exclamation, and stared with all my might at the strangest sight I ever saw. There was a violent commotion in the sea right where the moon's rays were concentrated, so great that, remembering our position, I was at first inclined to alarm all hands; for I had often heard of volcanic islands suddenly lifting their heads from the depths below, or dis-

appearing in a moment, and, with Sumatra's chain of active volcanoes so near, I felt doubtful indeed of what was now happening. Getting the night glasses out of the cabin scuttle, where they were always hung in readiness, I focussed them on the troubled spot, perfectly satisfied by a short examination that neither volcano nor earthquake had anything to do with what was going on; yet so vast were the forces engaged that I might well have been excused for my first supposition. A very large sperm whale was locked in deadly conflict with a cuttle-fish, or squid, almost as large as himself, whose interminable tentacles seemed to enlace the whole of his great body. The head of the whale especially seemed a perfect network of writhing arms—naturally, I suppose, for it appeared as if the whale had the tail part of the mollusc in his jaws, and, in a businesslike, methodical way, was sawing through it. By the side of the black columnar head of the whale appeared the head of the great squid, as awful an object as one could well imagine even in a fevered dream. Judging as carefully as possible, I estimated it to be at least as large as one of our pipes, which contained 350 gallons; but it may have been, and probably was, a good deal larger. The eyes were very remarkable from their size and blackness, which, contrasted with the livid whiteness of the head, made their appearance all the more striking. They were at least a foot in diameter, and seen under such conditions looked decidedly eerie and hobgoblin-like. All around the combatants were numerous sharks, like jackals around a lion, ready to share the feast and apparently assisting in the destruction of the huge cephalopod. So the titanic struggle went on in perfect silence as far as we were concerned, because, even had there been any noise, our distance from the scene of conflict would not have permitted us to hear it.

It is quite possible that the animal observed was an octopus, which would better fit the geographical position of the conflict than the squid. Such a fight is depicted in chapter 11, The Autobiography of a Sperm Whale, Frank T. Bullen's "Denizens of the Deep," from which we have taken plate 17.

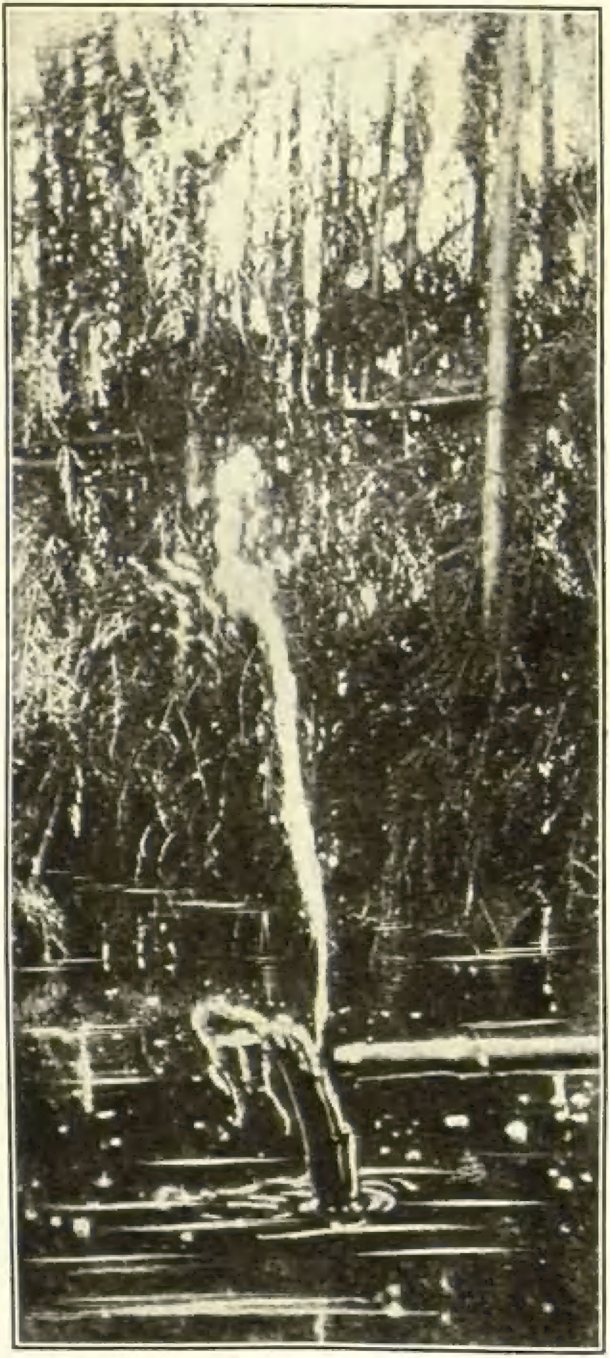
It is probable, from various observations, that this and the other species of squids are partially nocturnal in their habits, or at least are more active in the night than in the day. Those that are caught in the pounds and weirs mostly enter in the night, evidently while swimming along the shores in "schools." They are often found in the morning stranded on the beaches in immense numbers, especially when there is a full moon, and it is thought by many of the fishermen that this is because, like many other nocturnal animals, they have the habit of turning toward and gazing at a bright light, and since they swim backwards they get ashore on the beaches opposite the position of the moon. This habit is also sometimes taken advantage of by the fishermen, who capture them for bait for cod fish; they go out in dark nights with torches in their boats and by advancing slowly toward a beach drive them ashore.

That Cephalopods furnished an attractive bait for fish was known to the ancients, for Aristotle tells us:

For this reason fishermen roast the fleshy parts of the cuttlefish and use it as bait on account of its smell, for fish are peculiarly attracted by it; they also bake the octopus and bait their fish baskets or weels with it entirely, as they say, on account of its smell.

A BATTLE BETWEEN A SPERM WHALE AND A GIANT OCTOPUS.

By permission, from "Denizens of the Deep," by Frank T. Bullen. Fleming H. Revell Co., publishers.



AN IMPALED SQUID SHOOTING WATER FROM THE SIPHON.

From "The Herring Weirs of the Maine Coast, Their Building and Their Use," by C. E. H., Country Life in America, August, 1904.

Our American cod fishermen will thoroughly agree with him, but they will say that baking or roasting is not essential, that salting even will do. Let us quote again from Simmonds's Commercial Products of the Sea:

> The squids form an important element in the North American fisheries. The common Loligo is the favorite food of the cod, and is therefore itself fished for bait. One-half of all the cod taken on the banks of Newfoundland are said to be caught by it. When the vast shoals of this mollusk approach the coast hundreds of vessels are ready to capture them, forming an extensive cuttle fishery, engaging 500 sail of French, English, and American ships. During violent gales of wind hundreds of tons of them are often thrown up together in beds on the flat beaches, the decay of which spreads an intolerable effluvium around. They must themselves be consumed in enormous numbers, for it has been estimated that a single squid will lay in one season 40,000 eggs.

A recent inquiry at the Bureau of Fisheries yielded the statement that about 3,000,000 pounds were captured annually, estimated to have a value of about $43,500. Sixty-six per cent are caught in traps in moss chiefly about Cape Cod, though many are obtained in the same manner all the way from Maine to Maryland. Considerable quantities also are obtained by American fishing vessels on the coasts of Canada and Newfoundland. These are not noted in the above statistics. To a considerable extent in former times, but only to a limited extent recently, squids have been caught by means of jigs, a collection of hooks arranged in circular form along a central weight. Jigs are dangled in the water at the end of short lines and attract the squids which are caught when they attempt to seize them.

On our west coast squids are caught for food purposes, being chiefly used by the Oriental element of the population. All through the south seas, the Philippines, and Japan, as well as the adjacent mainland countries, one may see split and dried cuttlefish hung in the stores and offered for sale as an element of proteid food. In the Mediterranean countries, where they are also used as food, they are usually pickled. Nor is the flesh the only element of commercial value, for the cuttlefish bone forms quite an element of commerce. It is not only used as an adjunct to the canary's cage, but in powdered form has served as a fine polishing powder, a fine dentifrice, and an ingredient of medicine. The ladies of ancient days knew it also, for they were accustomed to use the burned product, known to them as pearl powder, as an aid to complexion. In later days this was even improved upon by the addition of a bit of carmine to form the so-called French rouge. Sepia and India ink have been already referred to and need no further mention here.

We will close our sketch with some extracts from a charming article, "First Photographs Ever Made of a Paper Nautilus," pub-

lished by Charles Frederick Holder, in Volume 15, No. 4, 1909, of Country Life in America, which gives one a glimpse of the marvelous beauty of some of these pirates of the deep.

The term paper nautilus suggests the dainty structure in which the animal lives at times—a fragile, involuted, vase-like object, deeply fluted and coiled, the keel or edge sharp, having double points, while all over the calcareous and pearly shell are deep graceful and branched radiations. The general color is a delicate gray, the opening in the side of nacre, heavily coated, in sharp contrast to the horny translucent shell paper. The keel is tinted a rich brown that often extends an inch or two up the side of the shell, which may be 2 or 8 or 9 inches across. The shell is not to be compared with the ordinary covering of mollusks, as it is not essential to the animal; it is only a dainty object having the shape of a shell, formed by the animal for the protection of its eggs. It is, then, a nest and in no way connected with the animal, as in the case of the pearly nautilus, where the animal forms partitions as it grows and is connected with them all by a fleshy pedicle or cord. The paper nautilus can dart out of its fairy ship at a second's notice.

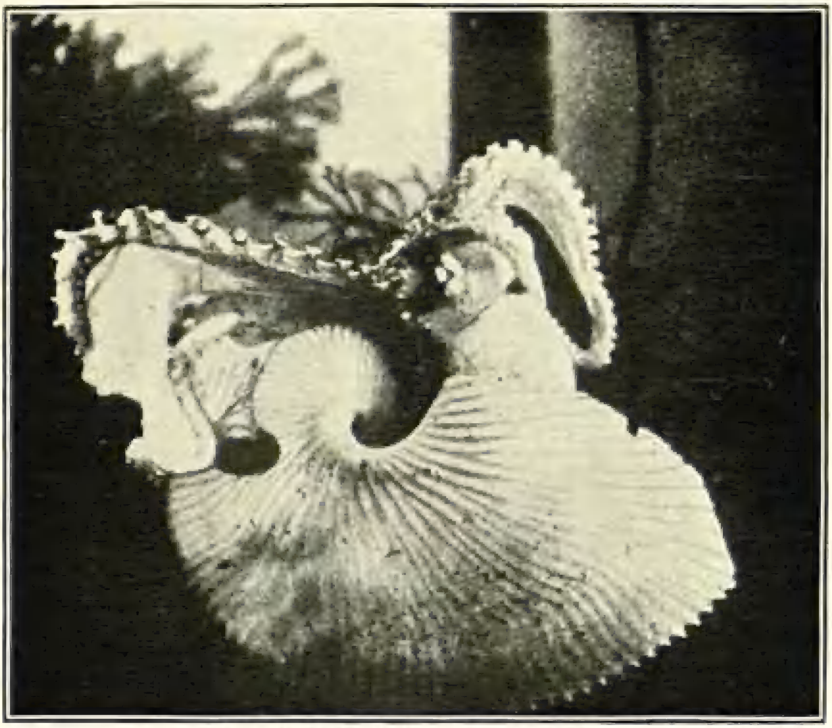
Glancing into the shell we may see a yellow bunch of miniature grapes hanging from the interior wall—the eggs—and perched in front of them is the argonaut, looking very much like an octopus or devilfish. From the number of empty shells found upon Santa Catalina beaches in winter and summer it might be assumed that the argonaut deserts the shell at times and lives a roving, octopuslike life.

In appearance it is one of the most beautiful of all animals as it rests in its shell, trembling with color, as waves of rose, yellow, green, violet, and all tints of brown are continually sweeping over it; now irised in the most delicate shade of blue, now brown or green, changing to rose, vivid scarlet, or molten silver. So sensitive is it that every convulsive movement of the mantle of my paper nautilus in taking water to breathe and forcing it out of the siphon caused a wave of color to pass over the entire body. When the water was taken in the color cells contracted, leaving it pale for a fraction of a second; when it was forced out they evidently relaxed and the entire surface was suffused with color to disappear as quickly, giving a continuous heat-lightning effect.

Of the three living specimens that I have kept in confinement one was 4 or 5 inches long, another 8 or 9. The small one was extremely active, leaving its shell to crawl about its prison and darting back with great agility, directing its funnel backward at the cluster of eggs hanging in the interior of the shell, always paying the most assiduous attention to them to prevent the intrusion of any parasite or enemy.

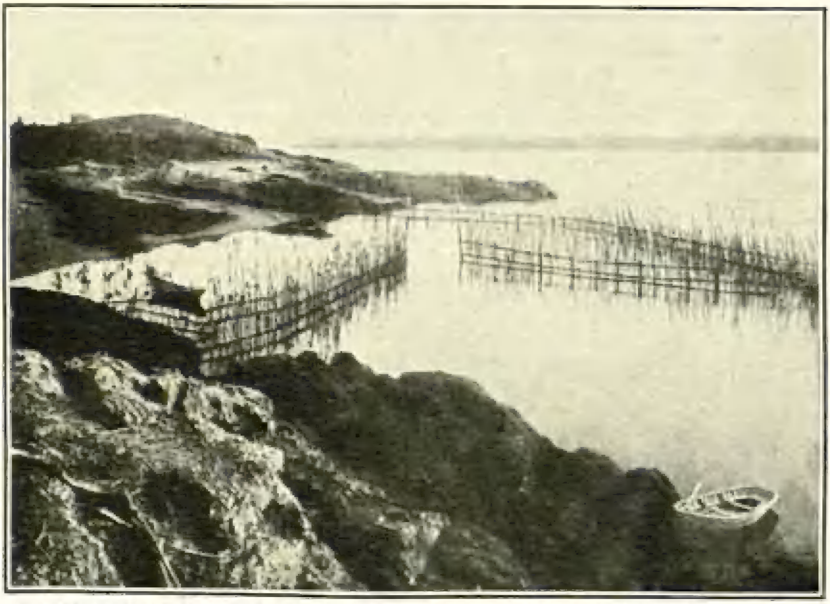
It would recline against the weed-covered rock watching me or eyeing my hand as it moved about, blushing, paling, displaying remarkable sensitiveness, and when I touched the shell would protest by pumping violently, shooting the shell backward and, if I held on, aiming the siphon at my hand and pumping water at it, on one occasion filling the water with an extraordinary volley or cloud of ink. But ordinarily this argonaut did not resent my friendly advances and when touched it would twine its tentacles about my fingers, hold them closely, and rise partly from the shell, the big black and silver staring eye evidently watching every movement.

The speed with which the argonaut could move backward, propelled by its siphon, was remarkable when seen from the side, but when it was observed from behind it was seen to be a perfect racing machine; the sharp keel of the shell covered by the extraordinary velamentous arms presented a perfectly



1. THE ARGONAUT AND HER EGG CASE.

From "First Photographs Ever Made of a Paper Nautilus," by Charles F. Holder, Country Life in America, February, 1909.



2. A FISH TRAP ON THE CAPE COD COAST, IN WHICH LARGE NUMBERS OF SQUID ARE CAUGHT.

From "King Herring: An Account of the World's Most Valuable Fish, etc.," by Hugh M. Smith. National Geographic Magazine, August, 1909.

smooth surface, and the slightest current from the siphon was sufficient to send it along, the entire animal being concealed, the tentacles not trailing behind, as often described. When the argonaut left the shell it crawled about in the position of an octopus, mouth down, but when in the shell its favorite position apparently was with its mouth pointing directly upward, the two dorsal or upper arms thrown back, or it would fasten itself to the glass of the tank by the two large arms and gradually expand them until they were as large as the shell itself, presenting a rippling ultramarine blue on the outer side and iridescent frosted silver on the other.

THE ECONOMIC IMPORTANCE OF THE DIATOMS.

By Albert Mann.

[With 6 plates.]

Scientific study is constantly giving emphasis to the fact that in nature there is little, if any, relationship between size and importance. Charles Darwin long ago made it plain that among the myriad of living creatures the earthworm plays a very important rôle in the economy of nature, especially as applied to mankind, and is in fact a greater animal than the elephant. The lowly grass outweighs in importance the loftiest tree of the forest. A brilliant series of discoveries led by Pasteur has revealed to us that the most gigantic power, in some cases beneficent, in others baleful, is exercised by the minutest of all living things, the bacteria. It is, therefore, not to be wondered at that the plants here under consideration, although as a class quite invisible to the naked eye, and many of them so minute that a hundred can be laid upon the head of a common pin, are at the same time of great economic importance.

But for a long time the attention of mankind was diverted from the more practical values that we are here to consider by that most striking characteristic of these plants, their surprising beauty and the unequaled complexity of their ornamentation. Coupled with their minuteness there is a daintiness of structure and an artistic diversity of design among the six thousand and odd species which has doubtless been the cause why until recent times they have been objects of merely esthetic interest. They have never been neglected, for from the time of the invention of the microscope they have been the darlings of the microscopists; but only to-day are they beginning to be recognized as an important factor in the welfare of the human race.

Each diatom plant secretes for itself an incasing box or investment of pure silica, somewhat as a clam or oyster secretes its shell; and these crystalline walls, within which the tiny living plant is housed, are sculptured and carved with such bewildering complexity of design and yet with such perfection of finish that their attractiveness has absorbed the attention of students to the detriment of their many less spectacular qualities.

Only one practical use has been developed from this esthetic study of the diatoms; they have been long recognized as the most accurate and satisfactory test objects for determining the perfection of microscopic lenses and accessories, the ability of any microscope to render visible the fine lace ornamentation which overspreads some of the species being the best index of its optical excellence. As a consequence of this, all microscopes are to-day tested with one or both of two species of diatoms, *Pleurosigma angulatum*, or *Amphipleura pellucida*.

One of the oldest of the economic uses of diatoms has been that of employing fossil diatom earth as a polishing powder, especially in metal work. These organisms appeared geologically about the middle of the Cretaceous period, and although, therefore, among the later of the now existing forms of plant life, their prolific multiplication has resulted, during former periods of time, in the formation of enormous fossil beds composed of the silica remains of these minute aquatic plants. Such beds are found all over the world, famous deposits being located at Luneburg, Germany; Bilin, Bohemia; Sendai, Japan; Ananino, Russia; Oamaru, New Zealand; Moron, Spain; Keene, N. H.; Nottingham, Md.; the coast of California, and many other places of minor importance. The first considerable fossil deposit of diatomaceous earth used was confused with a polishing material called "rottenstone," mined at Tripoli, in Africa, and it was therefore referred to in commerce by the same name, "Tripoli powder," and is in fact so sold in drug stores at the present time. Its high abrasive value comes from the fact that the material, silica, has a high degree of hardness and the grain of the diatom powder is so fine as to produce as a polish the highest luster. Its extreme fineness of texture is shown by a computation made by Ehrenberg, that in 1 cubic inch of the Bilin diatom earth there are 40,000,000 individuals.

This abrasive quality of the diatoms has led to their use for other purposes than metal polishing, as for example, for tooth powder. One of the widely advertised tooth powder preparations upon the market is composed entirely of diatomaceous earth. It can not be said that this is a good material for the purpose, as the cutting quality of this siliceous substance is too great to be used constantly upon the thin layer of enamel of the teeth. It is, however, interesting to think that many of the users of this diatom dentifrice would be amazed if they could see the thousands of exquisite gem-like organisms lying upon their tooth brush and used as a toilet preparation.

As a curious instance of perverted use, it might be well here to mention the fact that diatomaceous earth was at one time extensively eaten by the impoverished and half-starved tribes inhabiting the remoter portions of eastern Europe and Asia. Generally the diatom

earth was mixed with flour, and although the nutritive value of this added substance is practically nothing, the advantage of its use was an actual one; because, when the normal requirement of the human stomach for a "square meal" is a quart, and the available flour for that meal is a half pint, the unfortunate consumer gets at least the semblance of a full dinner by adding to his food supply three times its volume of harmless and inert matter. This is probably the explanation of the custom of those tribes known as the "earth eaters."

A number of years ago and shortly after the invention of nitroglycerine, the diatoms came into an economic use of great importance, namely, the manufacture of dynamite. This substance, so great a blessing and a curse to mankind, is essentially nothing but nitroglycerine absorbed into the cavities of dried diatom earth. As each diatom plant is a microscopically small silica box, the walls of which are perforated with intensely minute openings, the diatom earth serves to isolate tiny particles of nitroglycerine in such a way as to render the liquid practically a solid and at the same time to obviate the dangerous quality of free nitroglycerine of exploding by means of shock and at low temperatures. To-day, although diatomaceous earth is used to a considerable extent as an element in nitroglycerine explosives, it has been somewhat replaced by other substances, as for example, wood meal.

If the meaning of the word economic is not too rigidly taken and may include our increased facility in certain lines of research, it is proper to mention among the economic uses of these plants their value in the determination of certain problems of oceanography, especially in the determination of the direction and the extent of the great ocean currents. Those familiar with this phase of research are aware of the great difficulties attendant upon the accurate measurement of the extent and speed of an ocean current, due to the fact that the vessel from which such observations have to be made is itself a drifting object, acted upon by the current in question, as well as by the wind and other forces difficult to compute. Could the ship be anchored, this disadvantage would vanish; but inasmuch as this phase of oceanographic research is carried on in the deep seas, anchoring is not practicable. These organisms, on account of their peculiar structure, composition, and size, lend themselves perfectly to studies of this kind. It is perhaps safe to say that they are the only organisms which meet fully the requirements. Being composed in part of an indestructible substance, they do not suffer the rapid decay of many of the microscopic organisms of the sea. This is equally true of other marine organisms incased in silica; but none of these have a second characteristic of the diatoms which is of equal importance, namely, a minuteness of size sufficient to enable them to be carried hundreds or thousands of miles by ocean currents. Such

animal denizens of the sea as the Radiolaria are as immortal as to their silica encasements as are the diatoms; but their larger bulk and more massive construction precipitates them to the bottom, while the diatoms are held in suspension like the finest dust for an indefinite distance. When we add to these two qualities a third one, the large number of well-defined species, differing in kind according to the parts of the world in which they are found, we see that the presence of these organisms in an ocean current, even thousands of miles from land, will often indicate the direction, the extent, and to some degree the speed of the current by which they are borne along. It should be here stated as a factor in this problem that the diatom flora of any part of the world is always peculiar to that locality, just as the land flora varies at different latitudes and on the different continents. Thus we have a north and south arctic, a north and south temperate, and a torrid diatom flora, which are in strong contrast to each other and which, wherever met with, indicate the place of their origin. In the same way the fresh-water forms, which are poured in large quantities into the sea by the rivers, are still more distinctive, and each section of the coast of our continent has at least some of these plants to be found nowhere else upon the earth.

The student of these minute plants is constantly made aware of this sharp distinction of the diatom flora of one part of the world from that of the rest. Let us take some examples: A recent study of some living material from the Hawaiian Islands yielded a large and elaborately ornamented diatom, *Biddulphia imperialis*, and search through diatom literature revealed this in an obscure monograph, where it was recorded that it also had been found "at the Sandwich Islands." Doubtless the locality of the original specimen was practically that of the one later found. Another species was named by a Philadelphia diatomist as having been found in a gathering at Magdalena Bay, Lower California, and marked as "very rare." The writer subsequently found it to be very plentiful in a dredging of the U. S. S. *Albatross*, and, by comparison with the record of the original discovery, it was shown that the two localities were within a mile of each other. The writer named a new species discovered in the Arctic Sea, and subsequently, in a study of the dust collected in pockets on the ice floes of the Arctic, this diatom was rediscovered; and on comparison it was found that the latitude and longitude of the two were practically identical. Material secured by the Smithsonian Institution adjacent to the openings of the Panama Canal and previous to its completion has yielded a great many remarkable forms. A rare species known as *Pleurosigma spectabile* occurs abundantly in one of the gatherings. This was previously reported by Prof. Grunow, of Vienna, as occurring along the coast of Brazil; that is to say, it is a coastal, middle Atlantic diatom. An even more

rare form known as *Campylostylus striatus* was recently rediscovered in an irrigation ditch leading from the Everglades, in Florida. It was first found by Mr. Shadbolt, of England, on some mahogany logs shipped to London from the shores of Honduras; in other words, it is a Gulf of Mexico diatom.

An argument, and doubtless a valid one, to support the theory of Prof. Nansen that a current passes northward from the Bering Strait across the north polar region and southward along the western shores of Norway is based upon the fact that the diatom flora of Bering Sea was found by Prof. Nansen to be singularly similar to that of Greenland and the Norwegian coast, thereby indicating a connection between these apparently remote localities. From such examples as the foregoing it is reasonable to believe that when the normal diatom floras of the different seas have been investigated and the local diatom floras of the shallower waters, and especially of the rivers of the land, shall be known, we can tell by samples taken at remote points of the ocean the parts of the earth traversed by the current in which are found the specimens in question. In this same way a problem of no little importance to ocean travel becomes one of easy and certain solution, namely, the area of contact between the cold Arctic water of the north and the warm waters of the Gulf Stream off the coast of Newfoundland, this contact being the cause of the dangerous fogs prevalent in that locality; for a sample of sea water taken anywhere in that neighborhood must reveal at once to a diatom expert whether the water came southward from the Arctic, or northward on the current of the Gulf Stream, or is a blending of the two.

A consideration of the economic value of the diatoms requires mention of some minor uses. The large diatom beds of the western part of the United States, and especially those along the Pacific coast, where there are cliffs several hundred feet in height almost wholly made of this material, are coming to be of commercial value because of the use of this substance as a substitute for asbestos or in combination with asbestos as a nonconducting coating for steam pipes, as a filler for refrigerators, and for many other uses where a noncombustible material is needed. Fossil diatom deposits are also of value to the art of pottery making, being combined with various other ingredients in the composition of certain grades of porcelains and glass.

There has recently come into notice another use for diatomaceous earth which bids fair to become of considerable value to medical science. The material is compressed into filters in the shape of hollow cylinders or plates to be used for the filtration of serums, toxins, and other sterile liquids of service in the modern treatment of diseases. The porosity and extreme fineness of this material,

coupled with its resistance to the action of acids and most solvents, renders it peculiarly well suited for this purpose.

A rather baleful use, at one time more extensive than at present, thanks to our pure-food laws, and reminding us of the "earth eaters" previously mentioned, was the employment of diatom earth as an adulterant of candies. A large diatomaceous earth deposit in the eastern United States which formerly did a thriving business along this line has been practically abandoned at the present time, because certain candy manufacturers who used this substance have been compelled to resort to other means for cheapening their product. It is only to be hoped that the substitute, whatever it is, is as little harmful to the consumer as was the diatom material.

It seems right to revert to the artistic beauty of these minute organisms, mentioned at the opening of this article, because their economic importance should not exclude their practical value to the arts in the matter of designs. Those who are familiar with these organisms find their great beauty consists not only in the delicate and complex tracery of their surfaces, surpassing in this respect the most ingenious arabesques of the Moor, but in the symmetry and great diversity of form and outline displayed by the members of this group. Nearly every symmetrical figure possible to curves and straight lines is represented in the diatoms. Elongated forms of graceful sigmoid structures, like Hogarth's line of beauty; thin crescents, like the face of the new moon; triangles, rigidly exact or varied by all graduations in the curvature or undulations of their sides and by the blunted or keenly sharpened character of their angles; spindles and ellipses of every variety of breadth and convexity; squares; double squares; stars, from five to twenty pointed; circles, so accurate in their periphery as to correct the errors of the most perfect mathematical instruments; and combinations of these fundamental figures are to be seen in great abundance. It comes about from these qualities that the diatoms have a suggestiveness in the matter of design that should render them of great value to certain kinds of the mechanical arts. Jewelers, though they might well despair of copying the elaborate perfection of some of these forms, could doubtless obtain useful suggestions for new figures in ornamentation. Manufacturers of articles of artistic quality, such as laces, wall papers, printed fabrics, oilcloths, etc., have ready-made in this gallery of art, the diatom flora, new and better ideas in designing; and, although the difficulty of obtaining and preparing diatom material for examination will limit their use in this field to some extent, the expense and toil of studying these objects would in many cases be well repaid.

At the risk of stretching a little the legitimate meaning of the title of this article, I wish to mention an element of importance connected

with these organisms, namely the value they have in throwing light upon a study of the differences between objects which are the product of mere mechanical construction and those the construction of which is coordinated with life. There are two things to be said in regard to the ornamentation of these plants. First, there is a perfection attained that is essentially absolute, and yet not so servilely exact to the type as to preclude the marks of individuality in each separate plant. Take a diatom, upon the surface of which are found some hundreds of glittering hemispherical beads, and a careful examination with the finest optical apparatus will discover no trace of crudity or irregularity in these hemispheres, each one being polished with a perfection and curved with an accuracy that is absolute; and yet it would be hard to find two individuals with the same number of beads. Among the thousands of these organisms that can be found in a spoonful of ooze dredged from the bottom of the sea and extending for thousands of miles beneath its waters, each separate form will show the same adherence to its type, the same perfection in its workmanship, but the same unmistakable individuality. This is not mere mechanical accuracy, but an accuracy associated in some unknown way with the qualities of that master builder within each cell, cytoplasm. The distinction here insisted on is precisely that between the flight of a bullet and the flight of a bird. It is well illustrated by the contrast to be seen in two of the accompanying illustrations; the sculpture of the living organism being shown in the figure of *Surirella baldjikii* copied from a photograph of that diatom, while the sculpture represented in the figure of a very similar diatom, *Surirella gracilis*, is a mechanically drawn counterfeit. How this living, almost formless jelly, plays the rôle of a peerless artificer it still remains for science to discover.

The other point in a study of the structure of these organisms is that the principles of design are sui generis and not at all associated with the substance of which they are composed. Silica, like all other mineral matter, has its definite lines and angles of crystallization; so that a particle from one part of the world fits with infinite nicety into a particle from any other part of the world. But this silica is woven on the looms of the diatoms into fabrics the mesh of which may be one of many thousand patterns, and no principle of curves and no combination of lines known to geometry correspond in the slightest degree to those found in the ornamentation of these plants. For example, a line may begin straight, bend gently into a curve, gradually or instantaneously be changed again and thus make up, with the thousands of other lines of the pattern, a variety of arrangement that has no relationship to the principles of mathematics. And yet there is a law within this apparent lawlessness so rigid that the individual species hold their characteristics through thousands of years, and

a *Navicula lyra* newly born in the Delaware River is a sister plant of a *Navicula lyra* born millions of years ago in the island of New Zealand. When, furthermore, it is borne in mind that we are here dealing with a unicellular organism the wonder becomes accentuated. Great complexity is also found in the flowers; but a flower consists of millions of cells and the complex of the whole is the sum total of the different parts. But here is one cell, with a single nucleus and microscopic droplet of cytoplasm, which builds for itself its own palace and is to itself its own architect. It is certainly not too much to say that here is a problem in the constructive resourcefulness of animate nature which must long woo and puzzle the observer.

There is at present a growing interest in the theory that the diatoms have contributed largely to the world's stock of petroleum. The author does not consider the evidence for this at all conclusive; as, among other things, there is a significant lack of contiguity between the world's great oil fields and the chief diatom deposits. But the subject is here mentioned because certain curious facts do lend a strong plausibility, if not a probability, to this theory. That these oils are of organic origin is generally recognized; and a physiological peculiarity of the diatoms, their enormous secretion of oil, explains why these tiny organisms suggest themselves to an explanation of the origin of petroleum. Most plants, during a part of their existence, manufacture more food-material, that is, building material, than is at the time required for growth; and this is temporarily stored up as a reserve supply. The chief reserve plant-food material is starch, with sugars, cellulose, inulin, asparagin, etc., as minor substances. But, outside of seeds and nuts, only a few plants store up their reserve supply in the form of oil. The diatom is perhaps the most remarkable in this respect. Living diatom plants will always be found to contain from two to ten shining oil globules, deep orange-yellow in color, and with a high refractive index. The bulk of this oil, in proportion to the size of the diatom, rarely falls below 5 per cent; and the author has samples of diatom material in which a careful measurement of the contained oil shows a proportion of 50 per cent. If we consider, therefore, the large extent of many of the known diatom deposits and their frequency in most parts of the world, it becomes evident that the potential volume of organic oil from this one source is very large. But, as above intimated, the application of cause and effect to the diatom-petroleum theory is at present very far from satisfactory.

In the diversified uses of the diatoms, if there be one that is of supreme importance, it is the value of these organisms as the great fundamental food supply of the marine world. In the sea as on the land, animal life is dependent upon plant life for the transformation

of the inorganic substances of the earth into organic materials that shall serve as food. The elements necessary to sustain life must be brought into certain chemical relationships, known as a class as organic substances, before the animal can draw upon these to supply its life processes. In other words, carbon, oxygen, hydrogen, nitrogen, phosphorus, potash, etc., will not juggle themselves into edible compounds. It is only by the alchemy of the green, chlorophyl-bearing plants that these combinations are brought about. The diatom is the smallest of all the green, chlorophyl-bearing plants; but despite its insignificant size, these lilliputian workers are so numerous that the sum total of their activity is almost beyond calculation. Prof. Kofoid has estimated that the average number of diatoms in 1 cubic meter of water in the Illinois River is 35,558,462. Thriving abundantly in all the waters of the earth, fresh and salt, from the north pole to the south, the countless myriads of these plants are turning the substances held in solution in the waters of the streams, lakes, and seas into living material and are doing this in that strange alembic where it always takes place, namely, the green, chlorophyl-grain. By harnessing in some way a sunbeam to its machinery it turns out from the crude material of mineral matter the vital material of plant tissue, and on this plant tissue there feeds directly or indirectly most of the animal life of the sea. Some of the minuter forms of economic value to mankind, like the smaller fishes (for example, the sardine) and the shellfish (clams and oysters) make these plants their principal if not their exclusive food. The teeming swarms of tiny animal creatures, of which the copepods may be cited as as an example, are the links between the diatoms and those other organisms which in turn prey upon them.

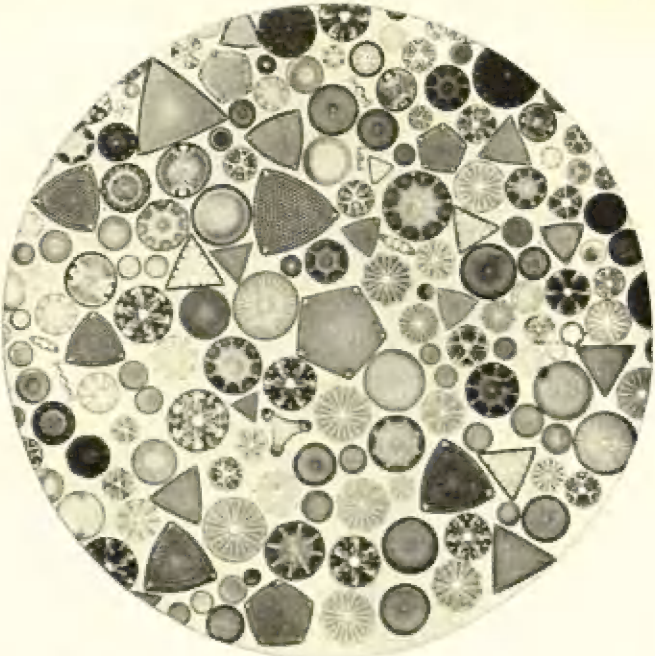
And thus, as upon the land the carnivore feeds upon the herbivore and the herbivore feeds upon the plant, so in the sea its animal denizens may be referred back in their food supply to the final source, the diatoms. It may therefore be said, without stretching the truth, that these plants are the *grass of the sea*, because they occupy the same important relationship toward the life of the sea that grass does toward the life of the land. It is not meant by this that other marine plants do not contribute to the store of animal food. Many of the brown and red seaweeds form the pastures of animal sea life; and one plant especially, the so-called eel grass, *Zostera marina*, is of great importance to those forms of life inhabiting the shallower waters along the shore and especially of the bays and estuaries indenting the coast. Although Zostera does not appear to be extensively preyed upon while it is growing, it becomes a highly nutritious feast for myriads of forms of animal life at the time of its decay. But its usefulness in this respect is greatly circumscribed because it is not available during the greater

portion of the year and is available only in those shallower waters in which it is fitted to flourish. Out upon the wide ocean, comprising roughly three-fourths of the surface of the globe, it is the diatom which is the plant par excellence as the supplier of animal food. It also shares this service with the other plants above mentioned in the shallower waters of the coast.

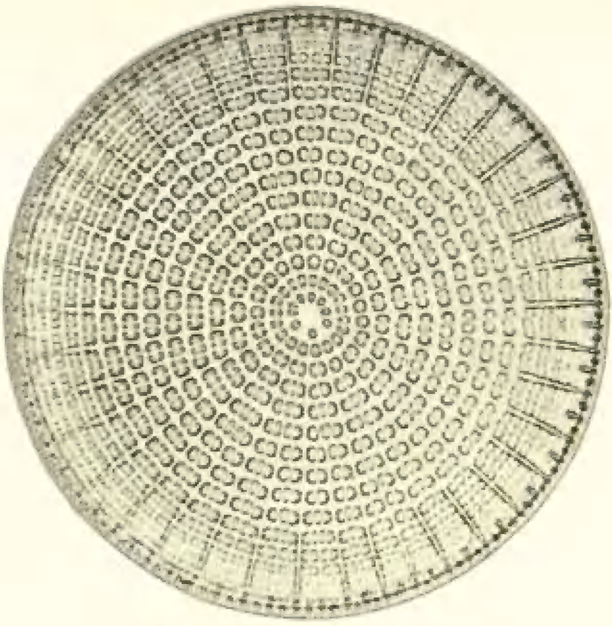
The full value of the diatoms in this particular is only recently being appreciated. It seems strange that the study of this important point has been so long deferred; as strange as if the stock raiser should have persistently neglected the study of those forage crops upon which the welfare of his stock depends. The enormous value of the fisheries to the world, to the inhabitants of all lands, is the measure of the importance of the study of these minute organisms, because of their intimate relationship to the problem of fish food. When the diatom flora of our coasts and of the high seas is sufficiently investigated we shall be in a position to understand better such problems as the migration of fishes and the prevalence of certain kinds in certain waters; and it is not improbable that means will be devised for augmenting the fish food supply through the diatoms, just as the science of agrostology works toward the betterment of the cattle raising industry.

As a single illustration of this point, let us take the teeming animal life of the Antarctic. Those who have seen illustrations of recent explorations near the South Pole were certainly impressed with the enormous fecundity of animal life in that region. It is strange therefore to note that this life is confined almost entirely to its waters; to learn that there are no land birds, no land animals, nor insects. This is because there is no plant life upon the shore. All bird life, all animal life is marine, penguins, gulls, petrels, and a long list of strictly aquatic animals. Now, in these waters of the Antarctic the plant life that is most prominent is the diatom. This plant, more than all others, is the explanation of the teeming life that inhabits those remote seas. The writer in investigating the diatoms of the Shackleton Expedition to the South Pole, found in most of the samples collected a larger percentage of diatoms than in any other samples known. Some dredgings made at McMurdo Bay were found to be at least 50 per cent edible diatomaceous material. No wonder therefore that the lower animal forms swarm in these waters and that the carnivorous animal forms of larger bulk are so prolific; for between them and extinction there stands the abundant and ever-present supply of plant food represented by the diatom flora.

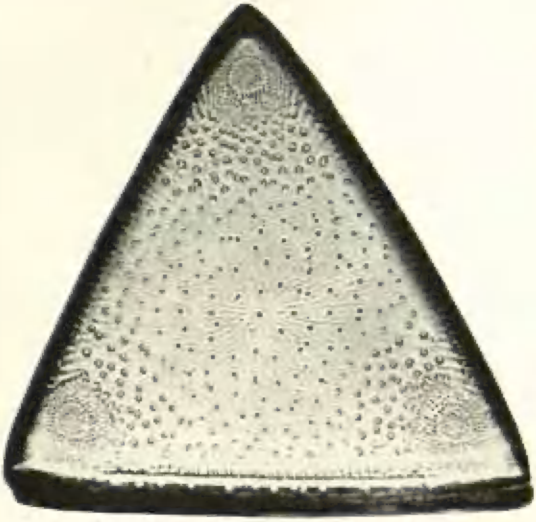
NOTE.—In the accompanying illustrations, with the exception of two figures, I am indebted for the use of the original photographs from nature, to the Hon. Alvey A. Adee, Washington, D. C. The magnifications of the group illustration is approximately 60 diameters, of the others from 600 to 750 diameters.



FOSSIL MARINE DIATOMS FROM HUNGARY. GROUPED FOR ILLUSTRATION.
MAGNIFIED ABOUT 60 TIMES.

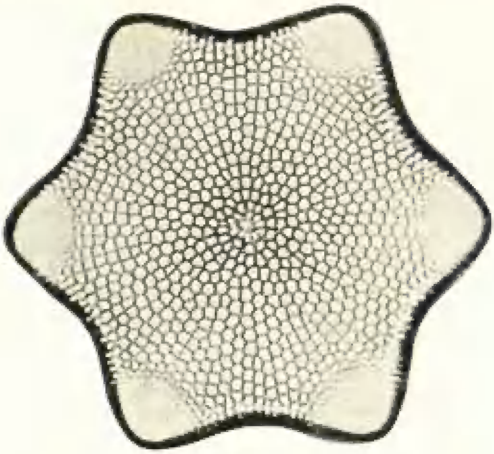


ARACHNOIDISCUS EHRENBERGII BAIL.

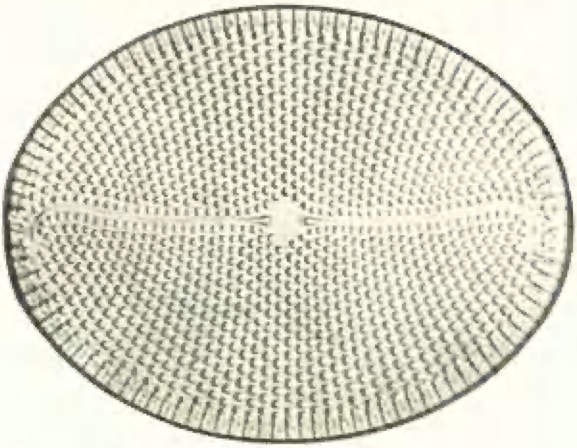


TRICERATIUM BALANIFERUM T. AND BR.

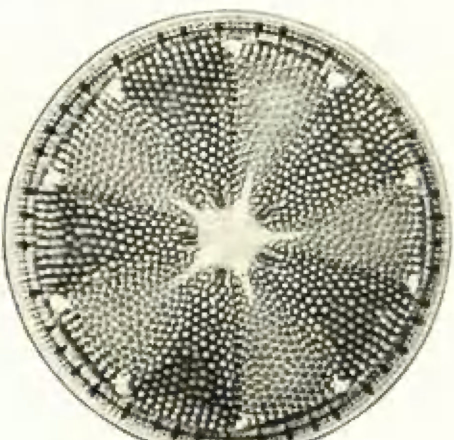
BIDDULPHIA GRUNOWII (JAN.).



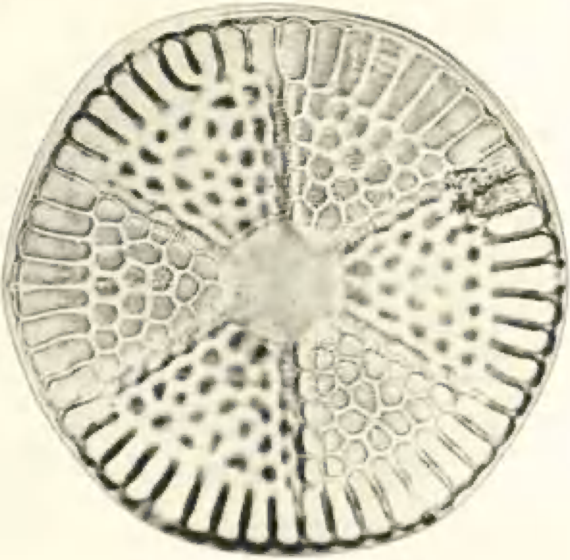
TRICERATIUM ARCTICUM BRIGHT. VAR.



ORTHONEIS SPLENDIDA (GREG.) GRUN.



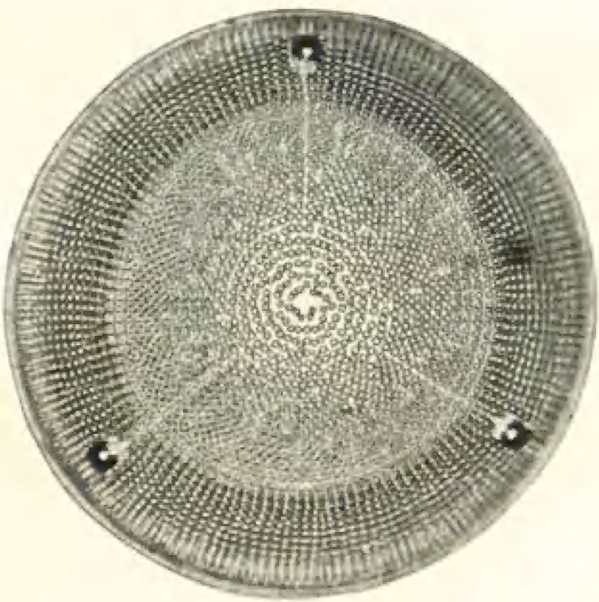
ACTINOPTYCHUS HELIOPELTA GRUN.



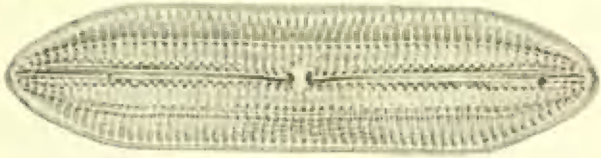
ACTINOPTYCHUS ASTER BRUN.

AULISCUS PRUINOSUS BAIL.

BIDDULPHIA PENTACRINUS (WALL.) V. H.

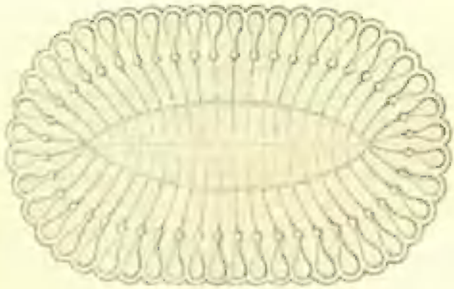


AULACODISCUS CONCENTRICUS MANN.



NAVICULA GEMMATA GREV.

SURIRELLA BALDJIKII NORM.



SURIRELLA GRACILIS O'ME.

NARCOTIC PLANTS AND STIMULANTS OF THE ANCIENT AMERICANS.[1]

By W. E. Safford.

Economic Botanist, U. S. Department of Agriculture.

[With 17 plates.]

The use of narcotic plants and stimulants was widely spread in both North and South America long before the discovery, not only for the purpose of exhilaration or intoxication, but also in connection with the practice of necromancy and in religious rituals and ceremonies accompanying the initiation of boys into the status of manhood. The companions of Columbus on his first voyage observed the custom of smoking cigars made of bundles of tobacco leaves as practiced by the aborigines of Hispaniola, or Haiti, and the same custom was observed on the Isthmus of Panama. The use of this plant was found to be very widely spread on the mainland of both North and South America. In Mexico tobacco was used in religious rituals like incense, and its leaves were chewed with lime. Though of subtropical origin, its cultivation extended as far north as the St. Lawrence River. The antiquity of tobacco smoking in North America is attested by the discovery of ceremonial tobacco pipes in prehistoric mounds and graves.

A narcotic snuff called cohoba, described by Ramon Pane, who accompanied Columbus on his second voyage, has been confused with tobacco. It was used by the natives of Hispaniola, who inhaled it through the nostrils by means of a bifurcated tube. Snuff similarly inhaled was afterwards found among several Indian tribes of South America. It proved to be a powder prepared from the seeds of a mimosalike tree, *Piptadenia peregrina*, to be described below.

Among the Aztecs, in addition to tobacco, two other narcotic plants, a small, fleshy spineless cactus mistaken by early writers for a fungus from the appearance of its dried discoid sections and the seeds of a species of Datura called ololiuhqui, were used by priests and magicians in their incantations. So holy were these plants held that collectors sent in quest of the cactus (peyotl) were consecrated with incense before starting on their journey, and it was

[1] Published by the authority of the Secretary of Agriculture.

considered a pious task to sweep the ground where the ololiuhqui grew. Among the Zuñis and the Indians of Arizona and Southern California the roots and other parts of a closely allied Datura were used in incantations and initiatory ceremonies. Among the Indians of Virginia the common *Datura stramonium* was used in a similar ceremony (huskinawing) to cause intoxication of candidates for initiation; and it is interesting to note that in the Andes of Peru a related tree datura, *Brugmansia sanguinea*, was used by the priests of the Temple of the Sun to induce exhilaration accompanied by supernatural visions.

Other narcotic plants belonging to the Solanaceae, or Nightshade Family, allied to the Mandragora and Hyoscyamus of the Old World, were species of Solandra, resembling climbing daturas with long trumpet-shaped flowers; Himeranthus and Jaborosa of South America, used as aphrodisiacs and in religious ceremonies; Salpichroa and Acnistus, with properties like those of *Atropa Belladonna;* and, in addition to these, a South American forest climber belonging to the Malpighiaceae described by Richard Spruce under the name *Banisteria Caapi.*

Among nerve stimulants used by American aborigines must be mentioned first of all *Erythroxylon Coca*, now of great importance as the source of cocaine; *Ilex paraguariensis*, the yerba mate, or Paraguay tea, and its very close ally of our Southern States, *Ilex vomitoria*, the basis of the celebrated "black drink"; *Theobroma Cacao*, from which chocolate is made; and *Paullinia Cupana*, the source of the cupana or curaná, of South America, which acts, somewhat like tea, as a wholesome stimulant.

Among alcoholic intoxicants were chicha or azua, prepared by fermenting gruel made from grains of maize or chenopodium, to which various fruit juices were sometimes added; tizwin, or teshuino, made by our southwestern Indians from sprouting maize or other grains, and also from mezquit pods or cactus fruits; and a fermented drink prepared in South America from the roots of mandioca. From the sap of certain species of palms wine was made in various parts of tropical America, and from century plants, or agaves, and yuccas the Mexicans made their fermented octli, or pulque. The art of distilling was unknown in ancient America, but with the fermented liquors above mentioned, often strengthened by narcotic herbs, roots, or seeds, many of the aboriginal tribes succeeded in "getting gloriously drunk," as one of the early Spanish writers declared. Some of them were addicted to most disgusting forms of debauchery long before they came under the degrading influence of civilization, so often deplored by travelers and missionaries.[1]

[1] See Spix and Martius. Reise in Brasilien, 3: 1075. 1831; and Robert Southey, History of Brazil, 3: 722–723. 1819.

TOBACCO.

(Plates 1 and 2.)

Tobacco is first mentioned in the account of Columbus's discovery of the New World. In the narrative published by Navarrete, under the date of November 6, 1492, is the following entry:

> Last night, says the admiral, came the two men whom he had sent to observe the interior of the island, and they told him how they had walked 12 leagues to a village of 50 houses. * * * On the road the two Christians encountered many people proceeding to their villages, men and women, holding in their hands a firebrand and herbs which they were accustomed to take in their incense burners.

In a footnote on the same page is added:

> In the Historia general de las Indias which he wrote, Bishop Casas refers with greater detail to this occurrence. "These two Christians met on the road (says he) many people who were proceeding to their villages, women and men, always the men with a firebrand in their hands and certain herbs to take in their incense burners, which are dry herbs wrapped in a certain leaf, also dry, after the manner of a musket made of paper which the boys make at the feast of Pascua del Espiritu Santo; and having lighted one end of it, at the other they suck or inhale, or receive within with the breath, that smoke, with which the body is soothed and which almost intoxicates, so that they do not feel fatigue. These muskets, or whatever we shall call them, they call tabacos. I knew Spaniards on this island of Hispaniola who were accustomed to taking them, and, being reproached for so doing because it was a vice, they replied that they could not stop the habit. I know not what savor or benefit they found in them. Here may be seen the origin of our cigars. Who would have ventured to say at that time that their consumption and use would one day become so common and general and that upon this new and strange vice there would be established one of the fattest revenues of the State?"[1]

USE OF TOBACCO BY THE MEXICANS.

By the ancient Mexicans tobacco was regarded as a sacred or magic herb. It was used in their religious rites and in ceremonies of various kinds in the form of incense. They also inhaled its smoke and chewed its leaves together with lime. In the Nahuatl language it was called yetl, as prepared for their fumigations it was called picietl; and the leaf of green tobacco together with lime, prepared for chewing was called tenexietl (from tenextli, lime, and yetl, tobacco). The last name is often modified into other forms, varying even in the writings of a single author, as tenegiete, tenechiete, etc., the Nahuatl X having the sound of the English SH (which is absent from the Spanish language), and the Spaniards having a tendency to drop the terminal L of Nahuatl words.

The plant itself, *Nicotiana tabacum*, was described by Dr. Nicolas Monardes of Seville, in 1574, and highly recommended by him for its

[1] Navarrete, Colleccion de los Viages de Descubrimientos, que hicieron por mar los Españoles desde fines del siglo XV. Tomo. 1. Viages de Colon: Almirantazgo de Castilla. pp. 50–51. 1825.

supposed medicinal virtues. After enumerating a long list of maladies which might be cured by it, and relating specific instances in which he had known it to be efficacious (very much after the manner of the testimonials published at the present day in connection with patent medicines), he describes its ceremonial use by the Indian priests, or necromancers. In this connection, however, since he speaks of its intoxicating effects, it is very probable that other narcotics were mixed with it. The custom of chewing it, as practiced by the Mexicans, he describes as follows:

> The Indians make use of tobacco to aid them to endure thirst as well as hunger, and to enable them to pass days without having necessity to eat or drink. When they have to journey across some desert or wilderness where neither water nor food is to be found, they use little pellets made of this tobacco. They take the leaves of it, and chew them, and as they go chewing them they go mixing with them a certain powder made of burnt clam shells, and go mixing them together in their mouth until they make a kind of paste, out of which they make little pellets a little larger than garbanzos and place them in the shade to dry, after which they keep them and use them in the following manner:
>
> When they are obliged to journey in regions where they do not expect to find water or food, they take one of those pellets and place it between the lower lip and the teeth, and they go along sucking it all the time that they are walking, and what they suck they swallow, and after this fashion they pass and journey three or four days without having necessity for food or drink; because they feel neither hunger nor thirst nor faintness which might hinder their journey.[1]

Padre de la Serna, who prepared a manual for instructing the missionaries sent to the Indians concerning witchcraft, necromancy, and idolatry, as practiced by the payni and titzitl of the Mexicans, speaks repeatedly of the use of tobacco (picietl) and lime-and-tobacco (tenexietl) in their various conjurations. This plant, to which the Mexicans ascribed divine honors, was invoked like the sacred ololiuhque and peyotl, which will be described later. In all cases the spirits of the plants, designated as brown or green or white, were called upon to cast out various maladies, also distinguished by colors, with threats if they failed and promises if they succeeded. In classifying these narcotics Padre Serna observes:

> They called by the name of "green spirit" the teneglete [tenexietl] which they prepared with lime, in order to give strength to the mouth, venerating it as though it were the guardian angel of travelers. Tobacco, since it did not cause hallucinations, was not held to possess the virtues of divination like those of the narcotic ololiuhqui [Datura] and peyotl [Lophophora]. The latter were held in such reverence by certain persons "forsaken by God" that they were carried about to serve as charms against all injuries.[1]

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[1] Monardes. "Historia medicinal de las Cosas que se traen de nuestras Indias Occidentales que sirven en Medicina." f. 30. 1574.

[2] See Jacinto de la Serna, "Manual de Ministros para el conocimiento de idolatrias y extirpacion de ellas." In Documentos Inéditos para la Historia de España, vol. 104, p. 165.

USE OF TOBACCO IN NORTH AMERICA.

The antiquity of the custom of tobacco smoking in North America is indicated by the discovery of tobacco pipes in graves and burial mounds in various parts of the United States. Two of these pipes are shown in the accompanying illustrations (figs. 1, 2). They are but a sample of many, often fashioned in the shape of mammals, birds, or reptiles, and sometimes of human beings, found in the Scioto Valley, where the writer was born. It was the discovery of objects like these in the mounds near Chillicothe, Ohio, that first instilled in him an interest in study of the origin and history of the aboriginal inhabitants of America.

FIG. 1.—Stone pipe from Indian Mound, near Chillicothe, Ohio, representing a cedar bird.

So widely spread was tobacco at the time of the discovery that, although a plant of subtropical origin, it was found in cultivation as far north as the St. Lawrence River. Indeed, one of the great tribes of North American Indians, known as the "Tobacco Nation," inhabited nine villages lying just south of Lake Huron. They took their name from the fact that they cultivated tobacco on a large scale and sold it to other tribes.[1]

The important part played by tobacco in many ceremonies of the North American Indians is too well known to need description in this place. In the South tobacco smoking often accompanied the ceremonial of the "black drink." At meetings of ambassadors, councils of nations, treaties of peace, and the reception of visitors, the calumet or pipe of peace was invariably circulated. The accompanying illustration (fig. 3) represents the stem of a ceremonial calumet, like that carried by Marquette during his travels among the Indians. In Virginia its cultivation was taken up on a large scale by the colonists.

FIG. 2.—Stone pipe in the form of a human head from the same locality.

Tobacco is undoubtedly the most important gift which America has presented to the world:

> No other visible and tangible product of Columbus's discovery has been so universally diffused among all kinds and conditions of men, even to the remotest nooks and corners of the habitable earth. Its serene and placid charm has everywhere proved irresistible, although from the outset its use has been frowned upon with an acerbity such as no other affair of hygiene has ever called forth. The first recorded mention of tobacco is in Columbus's diary for November 20, 1492 [Nov. 6, according to Navarrete]. The use of it was soon introduced

[1] It is interesting to note that in 1914 10,000,000 pounds of tobacco were produced in the Provinces of Quebec and Ontario.

into the Spanish Peninsula, and about 1560 the French ambassador at Lisbon, Jean Nicot, sent some of the fragrant herb into France, where it was named in honor of him Nicotina. It seems to have been first brought to England by Lane's returning colonists in 1586, and early in the seventeenth century it was becoming fashionable to smoke, in spite of the bull of Pope Urban VIII and King James's "Counterblast to Tobacco." Everyone will remember how that royal author characterized smoking as "a custom loathsome to the eye, hateful to the nose, harmful to the brain, dangerous to the lungs, and in the black stinking fume thereof nearest resembling the horrible Stygian smoke of the pit that is bottomless."[1]

In spite of all efforts to discourage its use and cultivation, tobacco soon became the principal staple of the New World, and was even

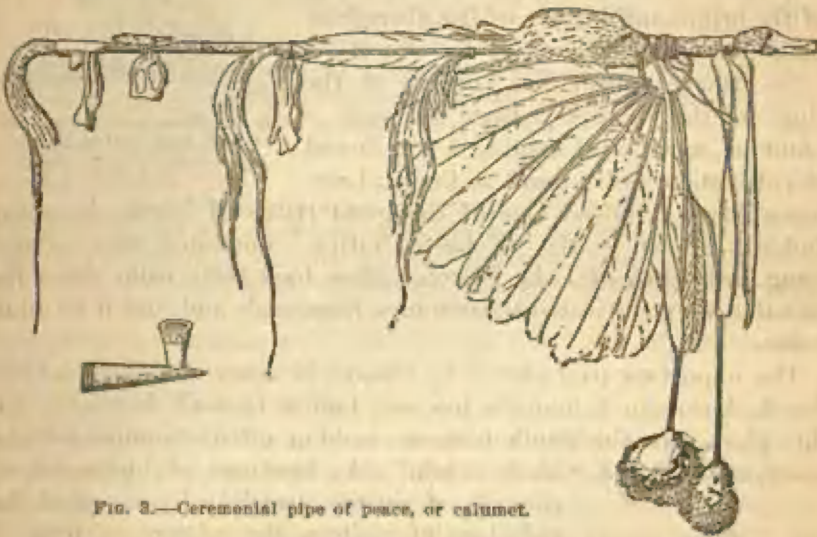

FIG. 3.—Ceremonial pipe of peace, or calumet.

used instead of gold and silver for currency. In 1619, owing to the scarcity of wives in Virginia a shipload of young women—

spinsters carefully selected and matronized (says Fiske) were sent to the colony. They had no difficulty in finding suitors, but no accepted suitor could claim his bride until he should pay the London Company 120 pounds of tobacco to defray the expenses of her voyage.[2]

Fiske calls attention to the important rôle which tobacco has played in the history of our country by repeating a remark of Moncure Conway: "A true history of tobacco would be the history of English and American liberty." Fiske continues:

It was tobacco that planted an English nation in Virginia. It was the desire to monopolize the tobacco trade that induced Charles I to recognize the House of Burgesses; discontent with the Navigation Act and its effect upon the tobacco trade was potent among the causes of Bacon's Rebellion; and so on

[1] Fiske, John. Old Virginia and her Neighbors, 1: 174–175. 1898.
[2] Fiske, op. cit., 1: 188–189.

down to the eve of Independence, when Patrick Henry won his first triumph in the famous Parson's Cause, in which the price of tobacco furnished the bone of contention, the Indian weed has been strangely implicated with the history of political freedom.[1]

Such a certain and steady demand was there for it that, like chocolate in Mexico, it became the currency of the colony.

The prices of all articles of merchandise were quoted in pounds of tobacco. In tobacco taxes were assessed and all wages and salaries were paid. This use of tobacco as a circulating medium and as a standard of values was begun in the earliest days of the colony, when coin was scarce, and the structure of society was simple enough to permit a temporary return toward the primitive practice of barter. Under such circumstances tobacco was obviously the article most sure to be used as money.[2] It was exchangeable for whatever anybody wanted in the shape of service or merchandise, and it was easily procured from the bountiful earth.[3]

COHOBA SNUFF OF THE ANCIENT HAITIANS.

(Plate 3.)

In addition to tobacco the companions of Columbus encountered another narcotic in Haiti, or Hispaniola, called cohoba. It was taken in the form of snuff, inhaled through the nostrils by means of a bifurcated tube. It was correctly described by Ramon Pane, appointed by the great admiral to report upon the superstitious beliefs of the islanders, and also by Las Casas, who was an eyewitness to the ceremonies accompanying its use. Subsequent writers, misled by Oviedo's incorrect statement that this substance was ignited and its smoke inhaled through the nostrils by the bifurcated tube, confused it with tobacco. It was in reality derived from the seeds of a mimosa-like tree, known botanically as *Piptadenia peregrina*. That it could not have been tobacco is apparent from the description of the physiological effects caused by it. All writers united in declaring that it induced a kind of intoxication or hypnotic state, accompanied by visions which were regarded by the natives as supernatural. While under its influence the necromancers, or priests, were supposed to hold communication with unseen powers, and their incoherent mutterings were regarded as prophesies or revelations of hidden things. In treating the sick the physicians made use of it to discover the cause of the malady or the person or spirit by whom the patient was bewitched. The snuff was called coxoba in the language of the islanders. This was rendered in the Italian orthography of the translation of Pane's description, "cogioba," and incorrectly transcribed as "cogiba," or "cojiba." In Spanish orthography it is written "cojoba."

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[1] Fiske. Old Virginia and her Neighbors, 2: 174. 1898.

[2] It is interesting to note that at a later epoch whisky distilled from maize was used in certain parts of the United States as currency, even for paying the salaries of school teachers and clergymen.

[3] Fiske, op. cit. p. 216.

In describing the idols of the islanders Pane gives the following account:

Those of wood are made in this fashion: When someone is going along on a journey he says he sees a tree which is moving its roots; and the man in a great fright stops and asks: "Who is it?" And he replies: "My name is Buhuitihu, and it will indicate who I am." And the man goes to the physician and tells him what he has seen, and the enchanter or wizard runs immediately to see the tree which the man has told him of and sits down by it, and he makes cogioba as we have described [above in the story of the four]. And when the cogioba is made he stands up on his feet and gives it all its titles as if it were some great lord, and he asks it: "Tell me who you are, and what you are doing here, and what you want of me, and why you have had me called. Tell me if you want me to cut you or if you want to come with me, and how you want me to carry you, and I will build you a cabin and add a property to it." Then that tree or cemi, become an idol or devil, replies to him, telling him the shape in which it wants to be made. And he cuts and makes it in the shape it has directed; builds its house for it, and gives the property, and many times in the year makes cogioba for it. This cogioba is to pray to it and to please it and to ask and to learn some things from the cemi, either evil or good, and in addition to ask it for wealth. And when they want to know if they will be victorious over their enemies they go into a cabin into which no one else goes except the principal men, and their chief is the first who begins to make cogioba and to make a noise; and while he is making cogioba no one of them who is in the company says anything till the chief has finished; but when he has finished his prayer he stands a while with his head inclined and his arms on his knees; then he lifts his head up and looks toward the sky and speaks. Then they all answer him with a loud voice, and when they have all spoken, giving thanks, he tells the vision that he has seen, intoxicated with the cogioba which he has inhaled through his nose, which goes up into his head. And he says that he has talked with the cemi and that they are to have a victory; or that his enemies will fly; or that there shall be a great loss of life, or wars, or famine, or some other such things which occur to him who is intoxicated to say. Consider what a state their brains are in, because they say the cabins seem to them to be turned upside down and that men are walking with their feet in the air. And this cogioba they make for cemis of stone and of wood as well as for the dead, as we have described above.[1]

Peter Martyr's account of the inhabitants of Hispaniola, in his De Orbe Novo, is simply a paraphrase of Fra Ramon's paper, in Latin. It adds nothing to his description of cohoba, but on the other hand it is misleading, since it refers to it as "an herb which they pound up and drink"; and though it states that the natives "absorb the intoxicating herb called cohobba, which is the same as that used by the bovites to excite their frenzy," it fails to specify that they breathed it through their nostrils by means of a forked tube. Nothing is said of the apparatus by which the snuff is taken, and indeed Ramon Pane himself neglects to give a description of it. Fernando Colombo, however, in his Historie (1571) states that for holding the snuff the natives had a finely wrought table of a

[1] Ramon Pane (1496), in appendix to Fernando Colombo's *Historie*, cap. XIX, p. 137a, 1571.

round form, resembling a trencher (come un tagliere), and that they took it by means of a bifurcated tube, "con una canna di due rami, che si mettono al naso."

The description of Las Casas is even more precise. The snuff tray he describes as "a plate, not flat but slightly concavish or deep, made of wood, so handsome, smooth, and pretty that it could not be very much more so were it made of gold or silver; it was almost black and polished like jet" (cuasi negro y lucio como de azabache). In describing the tube he says:

The tube was fashioned the size of a flute and was quite hollow, like a flute. From two-thirds of its length onward it divided by means of two hollow canes, just as we open the two middle fingers, leaving out the thumb, with the hand extended. The ends of these two canes inserted into the windows of the nostrils and the base of the flute, let us say, into the powder on the plate, they would draw in their breath and snuffing up, would receive through the nostrils as much of the powder as they wished to take, which, when taken, would go at once to the brain, almost as though they had drunk strong wine; for they would become drunk or almost drunk * * *. It was their custom, in coming together to decide difficult matters, such as the maneuvers of one of their war parties, or the performance of other things which they deemed important, to make their cohoba and with it intoxicate themselves or nearly so to do * * *. I saw these people on several occasions celebrate their cohoba, and it was an interesting spectacle to witness how they took it and what they spake. The chief began the ceremony, and while he was engaged all remained silent. When he had taken his cohoba (that is, when he had snuffed up the powder through his nostrils, as I have described), they being seated on certain handsomely carved low benches which they called duohos (the first syllable long), he remained silent for a while with his head inclined to one side and his arms placed on his knees. Then he raised his face heavenward, uttering certain words which must have been his prayer to the true God, or to him whom he held as God; after which all responded, almost as we do when we say amen; and this they did with a loud voice or sound. Then they gave thanks and said to him certain complimentary things, entreating his benevolence and begging him to reveal to them what he had seen. He described to them his vision, saying that the Cemi had spoken to him and had predicted good times or the contrary, or that children were to be born or to die, or that there was to be some dispute with their neighbors, and other things which might come to his imagination, all disturbed with that intoxication; or if perhaps without it, what the devil, to deceive them and win them to his worship, had brought to them.[1]

The snuff itself was described by Las Casas as "finely ground and of the color of cinnamon or powdered henna" (de color de canela ó de alheña molida).[2]

[1] Las Casas. Apol. Hist. de las Indias, Chap. 166, pp. 445–446, ed. Serrano y Saenz, Madrid. 1909.

[2] Alheña is the name of the so-called Egyptian privet, *Lawsonia inermis*, the powdered leaves of which, called henna, were used by the Egyptians for coloring their finger-nails. The fragrant flowers of this plant are the principal source of the perfume wafted by the breezes of "Araby the Blest."

THE COHOBA TREE STILL PERSISTS IN HAITI.

That a substance with the intoxicating effects of cohoba should have been identified with tobacco seems strange; but if not tobacco, what could have been its origin? Is the custom of taking a narcotic snuff by means of bifurcated tube still in existence in any part of America? If so, from what plant is the snuff prepared, and is this plant to be found growing on the island of Haiti? These questions may be answered as follows: The custom of taking a narcotic snuff still prevails in various localities of South America, showing that at one time it must have been widely spread. In inhaling it some tribes used bifurcated tubes which correspond very closely with the descriptions of those used in Hispaniola (fig. 4). The plant from which the snuff is derived is *Piptadenia peregrina*, a tree which grows both spontaneously and in cultivation on the banks of the Orinoco and Amazon Rivers and their tributaries. This tree does grow on the island of Hispaniola, or Haiti, as well as upon the neighboring island of Porto Rico and several other of the Antilles, and—most interesting and convincing of all facts connected with it—it still bears the name cohoba, which was applied in ancient times both to the snuff itself and to the ceremonial practice of using it.

FIG. 4.—Forked tube for inhaling narcotic Piptadenia snuff through the nose.

In connection with his studies of the plants used by the aborigines of America, the writer encountered various narratives of travelers in South America in which ceremonial snuff taking by savage tribes by means of bifurcated tubes was described. In all cases the snuff was made from the seeds of *Piptadenia peregrina*, the tree called Cohoba in Haiti. Among the writers who bear testimony to this practice are Padre Gumilla, in his Orinoco Ilustrado (1741); M. de la Condamine in his interesting Relation, published in the Memoires de l'Academie Royale des Sciences, Année 1745; Humboldt and Bonpland in their Voyage aux Régions Equinoxiales (1819), and Spix and Martius, Reise in Brasilien (1831). One of the most interesting features in connection with the use of the seeds of Piptadenia is described by Spix and Martius—the use of an infusion made from them as an enema. This was accomplished by means of pear-shaped rubber syringes, which, according to M. de la Condamine, were passed around to guests at ceremonial feasts. In various parts of South America the snuff was called niopa, ñupa, curupa, curuba, and paricá; and a similar or identical snuff, also made from Piptadenia seeds, was called cebil or sebil in Argentina and vilca, huillca, or willca in Peru.

For a full account of this interesting narcotic the reader is referred to the author's recent paper, "Identity of Cohoba, the narcotic snuff of ancient Haiti," published in the Journal of the Washington Academy of Sciences, volume 6, pages 547 to 562. It is remarkable that the identity of cohoba, mentioned in the very first account of the ethnology of the aboriginal inhabitants of the New World, should have remained unknown for three centuries, and more remarkable still that the seeds of *Piptadenia peregrina*, known to possess violent narcotic properties, should never have been studied by chemists. Humboldt was so much surprised on finding that the source of the snuff was a leguminous seed that he suggested the possibility of its intoxicating effects being due to the admixture of lime with it, but Richard Spruce, who saw the snuff prepared without lime, showed that this supposition was erroneous. It is not so strange, as Humboldt would indicate, that seeds of Leguminosæ should possess narcotic properties. The scarlet seeds of *Sophora secundiflora*, or *Broussonetia secundiflora*, of Texas and northern Mexico, are also very narcotic and are still used by certain Indian tribes for ceremonial purposes, as described below.

THE RED BEAN OF NORTHERN MEXICO AND TEXAS.

(Plate 3.)

Broussonetia secundiflora, described and figured by Ortega in 1798 from a plant growing in the Royal Garden at Madrid, but more commonly known by the name *Sophora secundiflora*, is a beautiful evergreen shrub or small tree with pinnately compound glossy leaves, racemes of violet-colored flowers, and indehiscent pods containing scarlet bean-like seeds. The latter have been studied chemically and are known to contain a narcotic poisonous alkaloid allied to cytisin, having a physiological effect very much like that of tobacco. From Texas, reports have been received that the seeds have poisoned children. The plant, though usually avoided by animals, is eaten by deer and goats, and the hard, glossy beans when swallowed whole are apparently harmless. In early days they were much used by certain tribes of Indians for making a narcotic decoction, and when ground to a powder were put in mescal, or Agave brandy, to make it more intoxicating; hence the name "mescal bean," which was formerly applied to them.

In early days these beans were so highly valued by the Indians of the Mexican border region that a string of them 6 feet long would be accepted in barter for a pony. According to Dr. Rothrock, who quotes Mr. Bellanger, of Texas, "the Indians near San Antonio used this bean as an intoxicant, half a bean producing delirious exhilaration followed by a sleep that lasts two or three days; and it is asserted that a whole bean would kill a man."[1]

[1] See Havard, V., Proc. U. S. Nat. Mus. 8: 500. 1885.

Mr. Alanson Skinner, in describing the Red Bean Dance of the Iowa Indians, says that among them this ancient rite far antedates the practice of eating peyote (*Lophophora Williamsii*) which they have more recently adopted. According to their traditions the society of red-bean dancers was founded by an Indian who while fasting dreamed that he received the secret from the deer: "for red beans (mescal) are sometimes found in deer's stomachs." The beans were prepared by first placing them before the fire until they turned yellow. Then they were taken and pounded up fine and made into a medicine brew. The members then danced all night. A little after midnight they began to drink the narcotic decoction, and continued to drink it until daybreak, when its effects became apparent in causing them to vomit. After vomiting and praying repeatedly they believed themselves ceremonially cleansed, the evil being having been expelled from their bodies. Members of the society, when they went to war, tied some of these red beans around their belts, deeming them efficacious as a charm to protect them from injury. The mancácutzi warúhawe, or "red-bean war-bundle," was regarded by the society as a sacred charm, the possession of which brought success in war, hunting, especially for the buffalo, and in horse racing.[1]

These beans are often confused with those of certain species of Erythrina, which are sometimes sold in their place in the markets of Mexico, but which are not at all narcotic. Sometimes both kinds are found mixed together in the same package. Both are known alike under the names colorin, frijolillo, and coral bean, on account of their similarity; but in southern Texas the seed of Broussonetia is known as Indian Bean, or mescal bean. The plants of Broussonetia and Erythrina do not in the least resemble each other, and there is no possibility of confusing either the flowers or the legumes of the two genera; so that when adulteration of the narcotic beans occurs it is undoubtedly intentional.

MEXICAN PLANT WORSHIP.

From the accounts of early writers it appears that the ancient Mexicans attributed to all plants a spirit not unlike that of animals or even of man himself. To certain plants special honors were paid; others were avoided with dread; while others, with no pronounced virtues or evil properties, were little noticed. An example is given by a Mexican writer of the homage paid to a certain tree cut down in order to form a bridge over a stream in Michoacan. The people of the village were called together by the governor and a religious service was held about a cross erected for the special ceremony, with candles burning before it and choristers assisting. A pro-

[1] Skinner, Alanson. Anthrop. Papers, Amer. Mus. Nat. Hist. 11: 718. 1915.

cession was formed which climbed the mountain where the tree was growing. When it fell there came an aged Indian woman who, taking a few of its branches, laid them on the trunk where it had been cut, and, consoling it with loving words, begged that it might not feel humiliated or angry; for they had chosen it on account of its magnificent stature and great strength, and it was destined to span a mighty river, so that all the people of the land of Michoacan might cross over upon it. And before dragging it away they placed upon the place where it had fallen a piece of lighted candle which had been left over from Holy Thursday, and they repeated in its honor a very solemn litany, sprinkling it with holy water and much pulque.[1] On the next day, having propitiated the spirit of the tree, they bore away the hewn beam to the bridge with much shouting and jubilation.[2]

The same author speaks of the veneration paid by the Mexicans to certain medicinal plants and to the narcotic ololiuhqui, the sacred nanacatl, the peyotl, and the picietl (tobacco), "to which they ascribe deity and with which they practice superstitions."

LOPHOPHORA WILLIAMSII, THE SO-CALLED SACRED MUSHROOM.

Bancroft, in referring to the narcotics used by the ancient Mexicans, mentions one which was believed by the early Spaniards to be a fungus. In writing of their ceremonial feasts, he says:

> Among the ingredients used to make their drinks more intoxicating the most powerful was the teonanacatl, "flesh of God," a kind of mushroom which excited the passions and caused the partaker to see snakes and divers other visions."[3]

This information was undoubtedly derived from accounts of the Spanish padres, one of whom, Bernardino Sahagun, writing before the year 1569, states that it was the Chichimeca Indians of the north who first discovered the properties and made use of these "evil mushroom which intoxicate like wine."[4]

They were gathered in the territory now northern Mexico and southern Texas, preserved by drying, and carried southward. The inhabitants of the Valley of Mexico knew them only in their dry state. It is also very probable that the early writers who recorded their use had seen them only when dry and never knew them as living plants. Francisco Hernandez, the physician sent by Philip II in 1570 to study the resources of Mexico, or New Spain, describes

[1] Fermented sap of the century plant (*Agave americana*), which also yields the strong distilled spirit called mescal.

[2] Jacinto de la Serna, "Manual de Ministros par el conocimiento de idolatrias y extirpacion de ellas." In Documentos inéditos para la Historia de España, vol. 104, pp. 159–160.

[3] Bancroft, H. H., Native Races, 2: 360. 1875.

[4] Sahagun, Bernardino (1499–1590). Hist. Nueva España (ed. Bustamante), 3: 118.

them under the heading "De nanacatl seu Fungorum genere." From the harmless white mushrooms (iztacnanacame), red mushrooms (tlapalnanacame), and yellow orbicular mushrooms (chimalnanacame), used for food, he distinguished them as teyhuinti, which signifies "intoxicating."[1]

In this connection it is interesting to note that this Nahuatl word, teyhuinti, or teyuinti (from yuinti, to be drunk), survives in the form of tejuino or tehuino in the State of Jalisco, Mexico, and tesuino or tizwin in the southwestern United States as the name of certain intoxicating drinks, the principal of which is a kind of beer brewed from malted maize.

DETERMINATION OF THE DRUG.

Three centuries of investigation have failed to reveal an endemic fungus used as an intoxicant in Mexico, nor is such a fungus mentioned either in works on mycology or pharmacography, yet the belief prevails even now that there is a narcotic Mexican fungus, and it is supported by Siméon in his monumental dictionary of the Nahuatl language, in which the following definitions occur:

Teonanacatl, espèce de petit champignon qui a mauvais gout, enivre et cause des hallucinations; il est médicinal contre les fièvres et la goutte.[2]

Teyuinti, qui enivre quelqu'un, enivrant; teyuinti nanacatl, champignon enivrant.[3]

In connection with his study of the economic plants of the Mexicans and the Indians of the southwestern United States the writer has sought diligently for a fungus having the properties attributed to the teonanacatl. As this narcotic was used by various tribes of Chichimecas, and the Chichimecas inhabited the territory situated in what is now northern Mexico and the southwestern United States, it was natural to look for the plant in this region. No such fungus, however, was discovered, but in its place a narcotic plant having properties exactly like those attributed to the teonanacatl was encountered; moreover, one form of this plant, when prepared as a drug, resembles a dried mushroom so remarkably that at first glance it will even deceive a mycologist (pl. 5). It is discoid in form and apparently peltate when seen from below; but the upper surface bears tufts of silky hairs, and a close inspection reveals the fact that it is the crown of a small fleshy spineless cactus which has been cut off and dried. The cactus in question, *Lophophora Williamsii*, when

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[1] "Quoniam inebrare solent, Teyhuinti nomine nuncupati sunt, et e fulvo in fuscum vergant colorem, risum inopportunum concitent, imaginemque citra risum inebriantium possint exhibere." Hernandez, Francisco (1514–1578). Hist. Pl. Nov. Hisp. (ed. Rom.) 2: 357. 1790.

[2] Siméon, Rémi, Dict. de la langue Nahuatl, p. 436, 1885.

[3] Op. cit., p. 412.

entire, resembles a carrot or radish rather than a mushroom, and when cut into longitudinal slices or irregular pieces, would never be mistaken for a fungus. Its chemical properties were investigated first by Dr. Lewin of Berlin, in 1888; afterward by Dr. Heffter of Leipzig. It was also studied by Drs. D. W. Prentiss and Francis P. Morgan of Washington. Alkaloids derived from it have been named lophophorine, anhalonine, and mezcaline.

IDENTITY WITH NARCOTIC PEYOTL.

Sahagun, who described the drugs of the ancient Mexicans from specimens brought to him by Indian herb doctors, failed to recognize the identity of the teonanacatl and peyotl of the Chichimecas, although he attributes similar narcotic properties to each. The latter he describes as follows:

> There is another herb, like tunas[1] of the earth; it is called peiotl; it is white; it is produced in the north country; those who eat or drink it see visions either frightful or laughable; this intoxication lasts two or three days and then ceases; it is a common food of the Chichimecas, for it sustains them and gives them courage to fight and not feel fear nor hunger nor thirst; and they say that it protects them from all danger.[2]

The plant itself was described by Hernandez as follows, under the heading De Peyotl Zacatecensi, seu radice molli et lanuginosa:

> The root is of nearly medium size, sending forth no branches nor leaves above ground, but with a certain woolliness adhering to it on account of which it could not be aptly figured by me. Both men and women are said to be harmed by it. It appears to be of a sweetish taste and moderately hot. Ground up and applied to painful joints it is said to give relief. Wonderful properties are attributed to this root (if any faith can be given to what is commonly said among them on this point). It causes those devouring it to be able to foresee and to predict things; such, for instance, as whether on the following day the enemy will make an attack upon them; or whether the weather will continue favorable; or to discern who has stolen from them some utensils or anything else; and other things of like nature which the Chichimecas really believe they have found out. On which account this root scarcely issues forth but conceals itself in the ground, as if it did not wish to harm those who discover it and eat it.[3]

From the above description, which applies perfectly to the plant from Zacatecas shown in plate 6, it follows that the peyotl zacatecensis of Hernandez is identical with *Lophophora Williamsii*. Specimens of the drug collected in northern Zacatecas by Dr. Francis E. Lloyd are shown in plate 7. They bear little resemblance to the mushroom-like buttons shown in plate 5, and it is not surprising that they should have been supposed to be distinct from the teonanacatl by the early Spanish writers.

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[1] Tuna, the Spanish name for the fruit of the Opuntia, or prickly pear.

[2] Sahagun (1499-1590). Hist. general de las cosas de Nueva España (ed. Bustamante) 3:241. 1830.

[3] Hernandez (1415-1578). De Hist. plant. Nov. Hisp. 3:70. 1790.

RAIZ DIABOLICA, OR DEVIL'S ROOT.

(Plates 6 and 7.)

By this term it was designated by Padre José Ortega, who tells of its use by the Cora Indians in his Historia del Nayarit, published anonymously at Barcelona in 1754, and republished under his own name in 1887. In describing their nocturnal dances he writes as follows:

> Close to the musician was seated the leader of the singing whose business it was to mark the time. Each of these had his assistants to take his place when he should become fatigued. Nearby was placed a tray filled with *peyote* which is a diabolical root (raiz diabolica) that is ground up and drunk by them so that they may not become weakened by the exhausting effects of so long a function, which they began by forming as large a circle of men and women as could occupy the space of ground that had been swept off for this purpose. One after the other went dancing in a ring or marking time with their feet, keeping in the middle the musician and the choirmaster whom they invited, and singing in the same unmusical tune (el mismo descompasado tono) that he set them. They would dance all night, from 5 o'clock in the evening to 7 o'clock in the morning, without stopping nor leaving the circle. When the dance was ended all stood who could hold themselves on their feet; for the majority from the peyote and the wine which they drank were unable to utilize their legs to hold themselves upright.[1]

The early missionaries were opposed to the drug not so much on account of its physiological effects upon the Indians but because of its connection with certain superstitious rites connected with their primitive religion. Eating the teonanacatl, or peyotl, was declared by the padres to be almost as grave a sin as eating human flesh. In a little religious manual published by Fray Bartholomé García in 1760, for the use of the missionaries to the Indians of San Antonio, Tex., the following questions, to be used in the confessional, are printed:

"Has comido carne de gente?" (Hast thou eaten flesh of man?)

"Has comido el peyote?" (Hast eaten the peyote?)[2]

The name teonanacatl is now obsolete. The drug is called by various names among the Indians using it—xicori by the Huicholes of Jalisco; hikori, or hikuli, by the Tarahumaris of Chihuahua; huatari by the Cora Indians of the Tepic Mountains; kamaba by the Tepehuanes of Durango; ho by the Mescalero Apaches, of New Mexico, who formerly ranged as far south as Coahuila; seni by the Kiowas; and wokowi by the Comanches, some of whom formerly lived in the State of Chihuahua. The name peyote has survived as a general commercial term; and the mushroomlike disks from the Rio Grande region are now widely spread among the northern In-

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[1] Ortega, Padre José (d. 1700). Hist. del Nayarit, pp. 22–23 (new ed.). 1887.

[2] García, Fr. Bartholomé. Manual para administrar los Santos Sacramentos, etc., p. 15. 1760.

dians of the United States under the misleading names of "mescal buttons" or "mescal beans," as well as under the Nahuatl name *peyote*.

CEREMONIAL USE BY THE INDIANS.

In a paper by the present writer published in the Journal of Heredity (vol. 6, No. 7, 1915) under the title, "An Aztec Narcotic," the author gives an account of the ceremonial use of this plant by various tribes of Indians. The first to bring to public notice its ceremonial use by existing tribes of Indians was James Mooney, of the Bureau of American Ethnology (1891). His attention had been directed to it while making investigation among the Kiowas, who are descendants of one of the tribes called Chichimecas by the Aztecs; and it is from the Chichimecas that they declared they had received the knowledge of this plant. Like the Aztecs, the Kiowas ascribed divine attributes to the drug, and their ceremony in connection with it was essentially religious. Not only the Kiowas, but other tribes now living in Oklahoma receive supplies of the narcotic from traders who bring it from the vicinity of Laredo, Tex., in olden times the land of the Chichimecas. Mr. Mooney's account was published in the Therapeutic Gazette of September 16, 1895. Other observers who mention the use of the narcotic Lophophora are Lumholtz, who describes the ceremonies of the Tarahumari Indians connected with it, and Leon Diguet, who tells of its use by the Huichol Indians of the mountains of Jalisco and Tepic.

Efforts have been made to prevent its spread among the Indians of the United States. An account of the recent prosecution of an Indian named Nah-qua-tah-tuck, of the Menominee Indian Reservation, Wis., for furnishing this drug to Indians of his tribe is given in the author's paper above cited. It developed in the trial that there is a regularly organized association among the Indians, called the Peyote Society, holding weekly services in which it is administered as a sort of communion; and it was claimed that its use put an end to the habit of drinking alcoholic beverages. Dr. Morgan, of the Bureau of Chemistry, gave to the court an account of his experiments bearing upon the physiological action of the narcotic.

At a meeting of the Lake Mohonk Conference in October, 1914, several papers relating to the effects of this drug upon the Indians were read and affidavits from two Omaha Indians were quoted. From one of the latter I take the following extracts:

AMONG THE OMAHA INDIANS.

At the meetings of the society "before they sing they pass the peyote around. They begin taking this medicine along about dark, and when they pass it, ask you how many you want, and they often try to persuade you to take more

than you want. The medicine does not work right away, but after it begins to take effect along toward midnight they begin to cry and sing and pray and stand and shake all over, and some of them just sit and stare. I used to sit in their range right along, and ate some of their medicine, but after I ate it the first time I was kind of afraid of it. It made me feel kind of dizzy and my heart was kind of thumping and I felt like crying. Some of them told me that this was because of my sins. It makes me nervous, and when I shut my eyes I kind of see something like an image or visions, and when my eyes are open I can't see it so plain. One of these fellows took 12 beans, or 12 peyote, sitting with some girls.

"After I have take 12 peyote I saw a mountain with roads leading to the top and people dressed in white going up these roads. I got very dizzy, and I began to see all kinds of colors, and arrows began to fly all around me. I began to perspire very freely. I asked to be taken out of doors. At that time it was 20° below zero. I felt better when I got out of doors. When I went in again I began to hear voices, just like they came from all over the ceiling, and I looked around in the other room and thought I heard women singing in there; but the women were not allowed to sing in the meetings usually, and so this was kind of strange. After eating 36 of these peyote I got just like drunk, only more so, and I felt kind of good, but more good than when I drink whisky; and then after that I began to see a big bunch of snakes crawling all around in front of me, and it was a feeling like as if I was cold came over me. The treasurer of the Sacred Peyote Society was sitting near me, and I asked him if he heard young kittens. It sounded as if they were right close to me; and then I sat still for a long time and I saw a big black cat coming toward me, and I felt him just like a tiger walking up on my legs toward me; and when I felt his claws I jumped back and kind of made a sound as if I was afraid, and he asked me to tell him what was the matter, so I told him after a while. I did not care to tell at first; but I made up my mind then, after what I saw, that I would not take another one of these peyotes if they gave me a $10 bill. In this Sacred Peyote Society they have a form of baptism and they baptize with the tea made from stewing the peyote, and they baptize 'in the name of the Father, and the Son, and the Holy Ghost,' the Holy Ghost being the peyote. Then you drink some of the tea, and they make signs on your forehead with the tea, and then take an eagle's wing and fan you with it. I heard an educated Indian, and he said in a meeting on Sunday morning, 'My friends, I am glad I can be here and worship this medicine with you; and we must organize a new church and have it run like the Mormon Church.'" [1]

USE IN ANCIENT MEXICO.

From the preceding description of a meeting of the Sacred Peyote Society held by the Winnebagos and Omahas in 1914, I turn back to the first account we have of the Teonanacatl feasts of the Aztecs, written by Padre Bernardino Sahagun in the sixteenth century—before Sir Francis Drake set out upon his voyage round the world—before tobacco, which the Mexicans also worshipped, was first brought to England:

The first thing eaten at the party was certain black mushrooms, which they call nanacatl, which intoxicate and cause visions to be seen, and even provoke

[1] Dalker, F. H., "Liquor and Peyote a Menace to the Indian," in Report of the Thirty-second Annual Lake Mohonk Conference, October, 1914, pp. 66, 67.

sensuousness. These they ate before the break of day, and they also drank cacao (chocolate) before dawn. The mushrooms they ate with sirup (of maguey sap), and when they began to feel the effect they began to dance; some sang; others wept because they were already intoxicated by the mushrooms; and some did not wish to sing, but seated themselves in their rooms and remained there as though meditating. Some had visions that they were dying and shed tears; others imagined that some wild beast was devouring them; others that they were capturing prisoners in warfare; others that they were rich; others that they had many slaves; others that they had committed adultery and were to have their heads broken as a penalty; others that they had been guilty of a theft, for which they were to be executed; and many other visions were seen by them. After the intoxication of the mushrooms had passed off they conversed with one another about the visions which they had seen.[1]

NARCOTIC DATURAS.

In early accounts of the aborigines of America, both north and south of the Equator, we find repeated references to the use of various daturas as narcotics. The Quichuas of Peru put the seeds of a datura into their azua, or fermented corn beer, to make it more intoxicating. They believed that the visions thus produced were supernatural and, like the remote Zuñis of New Mexico, they resorted to datura seeds in order to divine the hiding place of some precious object or to detect the thief who had stolen it. The professional Indian hechiceros of Spanish America were prosecuted by the church authorities for using narcotics in their practices of idolatry and witchcraft, very much as were the dhatura doctors of India for dispensing datura to criminals; and in the New World, as in the Old World, datura seeds were administered in various ways as a love potion or aphrodisiac. Another remarkable parallel may be seen in the religious use of the drug. Among the Aztecs the seeds of a certain datura were held sacred and the spirit of the plant was invoked to expel evil spirits, recalling the exhortations of the priests, or physicians, of ancient Babylon and the necromancers of mediæval Europe. In the Andes of South America Indian priests used datura seeds to produce delirium, recalling the use of intoxicants to induce frenzy by the Pythiæ in consulting the famous oracle of Apollo at Delphi.

M. de la Condamine, while exploring the Rio Marañon in 1743, found the Omagua Indians inhabiting the banks of that river addicted to narcotics, one of which was referred by him to *Datura arborea*, the plant "called by the Spaniards floripondio, with flowers shaped like a drooping bell, which has been described by Père Feuillée."[2] Miss Alice Eastwood, while exploring southeastern Utah, came upon an abundance of *D. meteloides*, and she

[1] Sahagun, Bernardino. Hist. Nueva España (ed. Bustamante) 2: 366. 1829.
[2] See Mem. de l'Acad. Roy. des Sciences, Année 1745, p. 430. 1749.

calls attention to the occurrence of its seed-pods "in the ruins of the ancient people who once filled this land and guarded every spring with towers of stone."[1] Stephen Powers found this same plant in use as an intoxicant and hypnotic by the priests and wizards of the Yokuts Indians inhabiting the banks of the Tule River and Lake Tulare in California.[2] Dr. Edward Palmer states that a decoction of the plant is given by certain California Indians to their young women to stimulate them in dancing, and that an extract of its root is used as an intoxicant by the Pah-Utes.[3] Other authorities state that the Mariposan Indians of California, including the Noches, or Yokuts, already mentioned, use a decoction of *Datura meteloides* in the ceremonial initiation of their youths into the status of manhood; and the medicine men of the Hualpais, or Walapais, belonging to the Yuman stock, indulge in a sacred intoxication by breaking up the leaves, twigs, and root of this plant to make a beverage which induces an exhilaration accompanied by prophetic utterances.[4]

FIG. 6.—Stone mortar, used by the California Indians for grinding root of *Datura meteloides* for ceremonial purposes.

THE SACRED OLOLIUHQUI OF THE AZTECS.

(Plate 8.)

This narcotic, beyond all doubt the seeds of a datura, or possibly two species of datura, played an important part in the religion of the ancient Mexicans and in the practices of their medicine men or necromancers.

Sahagun, about 1569, called attention to this plant in the following words:

> There is an herb which is called coatlxoxouhqui [green snake weed]. It produces a seed called ololiuhqui which intoxicates and causes madness (enloquece). It is administered in potions in order to cause harm to those who are objects of hatred. Those who eat it have visions of fearful things. Magicians or those who wish to harm some one administer it in food or drink. This herb is medicinal, and its seed is used as a remedy for gout, ground up and applied to the part affected.[5]

In other accounts it is stated that in Mexico it was believed that this plant, like the peyotl would give to those who ate it the power of second sight and prophecy, by means of which they could discover the identity of a thief, if an object had been stolen, or could predict the outcome of a war or the intended attack of a hostile tribe.

In the descriptions of ololiuhqui there are many discrepancies, owing possibly to the fact that the same name was applied to two or

[1] Zoe, 3: 360. 1892.
[2] See Contr. North Amer. Ethn. 3: 380 and 428. 1877.
[3] Amer. Nat. 12: 650. 1878.
[4] See Bourke, John G. On the Border with Crook, p. 165. 1892.
[5] Sahagun, Bernardino de. Hist. Gen. de las Cosas de Nueva España, 3: 241 (ed. Bustamante), Mexico. 1830.

more plants with flowers resembling morning-glories. Hernandez (1514–1578) in all probability never saw it growing, and figured it as an Ipomoea, but he indicates its relationship by suggesting that it may be the same as the *Solanum maniacum* of Dioscorides, and Padre Serna, who likewise never noticed the plant itself, described the seeds as resembling lentils (semilla a modo de lantejas que llaman ololiuhqui). It is interesting to note that Acosta makes the same comparisons in his description of the East Indian *Datura metel*, saying that it has flowers like the plant called in Spain correguela mayor (greater convolvulus) and that its fruit is filled with seed of the size of lentils (todo lleno de una simiénte del tamaño de lentejas). Great veneration was paid by the Mexicans to the ololiuhqui as well as to tobacco (picietl) and to the narcotic teonanacatl, or peyotl (*Lophophora Williamsii*).[1] To these plants according to Padre Serna, the Mexicans ascribed divine powers, with which they practiced magic.

The methods of the Aztec titzitl, or herb-doctors, in casting out the evil spirits causing sickness, are remarkably like those employed by the priests of ancient Babylon and of the island of Haiti. The spirit of the powerful Ololiuhqui was invoked in the following words:

> Come now, come hither, Green Woman; behold the green heat [fever] and the brown heat; remove thou the flaming or scarlet heat, the yellow heat, or by this token I send thee to the seven caves. And, I do command thee, put it not off till tomorrow or another day; for sooner or later thou wilt be compelled to do it. Who is the god—the so powerful and superior one—who can destroy the work of thy hands? It is I who command it, I the prince of enchantment.[2]

THE USE OF DATURA METELOIDES BY THE ZUÑIS.

(Plate 9.)

It seems strange that the property of giving the power of second sight and prophecy, attributed to the ololiuhqui by the Mexicans, should be similarly attributed by the ancient Peruvians to *Datura sanguinea* and by the Zuñis of New Mexico, so far remote from them, to *D. meteloides*, with which the ololiuhqui is undoubtedly identical. Mrs. Matilda Coxe Stevenson in her Ethnobotany of the Zuñi Indians relates a pretty legend connected with "this precious plant, which is believed to have once been a boy and a girl," resembling a story from Ovid's Metamorphoses. Plate 9 is the photograph of flowers and fruit of a specimen of *Datura meteloides*, two-thirds natural size, made at Sacaton, Arizona, by Mr. Harold Murphy. It was secured by the writer through the courtesy of Mr. Thomas H. Kearney, of

[1] For an account of the ceremonial use of the last-named plant see the writer's paper on "An Aztec Narcotic" in Journal of Heredity, 6: 291–311. 1915.

[2] See Jacinto de la Serna, "Manual de Ministros para el conocimiento de idolatrias y extirpacion de ellas." In Documentos inéditos para la Historia de España, vol. 104, pp. 159–160.

the Bureau of Plant Industry. The plant is identical in all respects with similar plants previously collected in various parts of Mexico and the southwestern United States by the late Dr. Edward Palmer, who called attention to the use of the plant at the present day by several tribes of Indians as a ceremonial and narcotic.

ORIGIN OF THE NAME JIMSON, OR JAMESTOWN WEED.

(Plate 10.)

The narcotic properties of *Datura stramonium* were known to our own southern Indians as well as to the Mexicans.[1] Hernandez calls attention to the fact that its fruit causes insanity if eaten incautiously. That this is true is shown by the following anecdote taken from Robert Beverly's History and Present State of Virginia, in his account "Of the Wild Fruits of the Country." It appears that the soldiers sent to Jamestown to quell the uprising known as Bacon's Rebellion (1676) gathered young plants of this species and cooked it as a potherb.

> The *James-Town* Weed (which resembles the Thorny Apple of *Peru*, and I take to be the Plant so call'd) is supposed to be one of the greatest Coolers in the World. This being an early Plant, was gather'd very young for a boil'd salad, by some of the Soldiers sent thither, to pacifie the Troubles of *Bacon*; and some of them eat plentifully of it, the Effect of which was a very pleasant Comedy; for they turn'd natural Fools upon it for several Days: One would blow up a Feather in the Air; another woul'd dart Straws at it with much Fury; and another stark naked was sitting up in a Corner, like a Monkey, grinning and making Mows at them; a Fourth would fondly kiss, and paw his Companions, and snear in their Faces, with a Countenance more antick, than any in a *Dutch* Droll. In this frantick Condition they were confined, lest they should in their Folly destroy themselves; though it was observed, that all their Actions were full of Innocence and good Nature. Indeed, they were not very cleanly; for they would have wallow'd in their own Excrements, if they had not been prevented. A Thousand such simple Tricks they play'd, and after Eleven Days, return'd themselves again, not remembring any thing that had pass'd.[2]

THE HUACA-CACHU OF PERU.

(Plate 11.)

The narcotic effects of *Datura sanguinea*, known in Peru as Huacacachu, or Yerba de Huaca, have been described by several travelers. Tschudi, who found it growing on the declivities of the Andes above the village of Matucanas, repeats the statement of Humboldt that from its fruit the Indians prepare a very powerful intoxicant which they call tonga, on which account the Spaniards named the plant borrachero. His account is as follows:

> The Indians believe that by drinking the tonga they are brought into communication with the spirits of their forefathers. I once had an opportunity

[1] Its active principle, daturine, has been identified with the alkaloid atropine, for which it is a perfect substitute. In 1916 one firm in the United States used one and a half million of pounds of this plant for the manufacture of atropine.

[2] [Beverly, Robert.] History and Present State of Virginia. Bk. 2, p. 24. 1705.

of observing an Indian under the influence of this drink. Shortly after having swallowed the beverage he fell into a heavy stupor; he sat with his eyes vacantly fixed on the ground, his mouth convulsively closed, and his nostrils dilated. In the course of about a quarter of an hour his eyes began to roll, foam issued from his half-opened lips, and his whole body was agitated by frightful convulsions. These violent symptoms having subsided, a profound sleep of several hours succeeded. In the evening I again saw this Indian. He was relating to a circle of attentive listeners the particulars of his vision, during which he alleged he had held communication with the spirits of his forefathers. He appeared very weak and exhausted.

In former times the Indian sorcerers, when they pretended to transport themselves into the presence of their deities, drank the juice of the thorn-apple in order to work themselves into a state of ecstasy. Though the establishment of Christianity has weaned the Indians from their idolatry, yet it has not banished their old superstitions. They still believe that they can hold communications with the spirits of their ancestors, and that they can obtain from them a clue to the treasures concealed in the huacas, or graves; hence the Indian name of the thorn-apple—huacacachu, or grave plant.

Humboldt and Bonpland, who collected *Datura sanguinea* on the banks of the Rio Mayo, in New Granada, state that the natives believe that the tonga prepared from this species to be more efficacious as a narcotic than that made from the white-flowered *Datura arborea* mentioned above. It is from the account of these travelers that the story of the Peruvian prophets is taken. The Temple of the Sun in which they officiated was at Sagamoza, in the interior of what is now Colombia. Dr. Santiago Cortés, in his account of the medicinal plants of the province of Cauca, Colombia, says that there are many stories and fables relating to this plant told by the natives.

COCA, THE SOURCE OF COCAINE.

(Plates 12 and 13.)

The most important stimulant of the ancient Peruvians was *Erythroxylon Coca*. Specimens of its 3-ribbed leaves were found by the writer in many prehistoric graves along the Peruvian coast, usually in bags suspended from the necks of mummies, or in bundles wrapped in cloth. Some of the coca bags, or pouches, were woven in beautiful and intricate designs (pl. 12), often representing conventional figures of birds, mammals, or fishes. All were accompanied by small gourds (a variety of *Cucurbita lagenaria*) containing lime, and a spatula by means of which the lime was dipped out. In place of lime, wood-ashes were sometimes used. The use of lime or ashes to set free the alkaloid contained in the leaves recalls the same custom in connection with the betel of Asia, the piptadenia snuff already mentioned, and the "green tobacco" of the Mexicans. That its efficacy should have been independently discovered by the primitive inhabitants of such widely separated regions is remarkable. The lime gourds were not infrequently ornamented, and in those discovered in some localities, especially at Arica, on the coast of northern Chile, the spatulæ were

of carved bone, many of them of beautiful designs, and the gourds were suspended by carved bone toggles resembling Japanese netsukes. Specimens of the latter may be seen in the Field Museum at Chicago. Two packages of leaves from Peruvian graves sent to the Smithsonian Institution by the late Henry Meigs, the builder of the great trans-Andine railway from Callao to Oroya, were found by the writer, one bearing the label "tobacco," the other "Paraguay tea." The contents of both of these packages proved to be coca leaves, easily identified by the pseudo-rib, extending on each side of the midrib from the base to the apex.

In the accompanying illustrations plate 13 is a photograph by Mr. Grover Bruce Gilbert of a specimen collected by Mr. O. F. Cook at Santa Ana, Peru, during his recent mission to South America.[1]

The leaves of *Erythroxylon Coca*, which from remote ages have been used by South American Indians as a stimulant, are the source of cocaine, now so widely used in surgery to deaden pain and also as a narcotic. Like other narcotic alkaloids, although it is a great blessing to the human race when wisely used, yet when abused it is a terrible curse. In Peru the use of coca by miners and cargueros is still common. There the entire leaf is used. In North Brazil, where it is also extensively used under the name ipadú, the leaves are ground to a fine powder. Spruce, who saw the process of preparing the leaves near the mouth of the Rio Negro in 1851, gives the following account of it in Hooker's Journal of Botany for July, 1853:

> The leaves of ipadú are pulled off the branches one by one and roasted on the mandiocca-oven, then pounded in a cylindrical mortar, 5 or 6 feet in height, made of the lower part of the trunk of the Pupunha or Peach Palm (*Guilielma speciosa*), the hard root forming the base and the soft inside being scooped out. It is made of this excessive length because of the impalpable nature of the powder, which would otherwise fly up and choke the operator; and it is buried a sufficient depth in the ground to allow of its being easily worked. The pestle is of proportionate length and is made of any hard wood. When the leaves are sufficiently pounded the powder is taken out with a small cuya fastened to the end of an arrow. A small quantity of tapioca, in powder, is mixed with it to give it consistency, and it is usual to add pounded ashes of Imba-úba or Drum tree (*Cecropia peltata*), which are saline and antiseptic. With a chew of ipadú in his cheek, renewed at intervals of a few hours, an Indian will go for days without food and sleep.
>
> In April, 1852, I assisted, much against my will, at an Indian feast in a little rocky island at the foot of the falls of the Rio Negro; for I had gone down the falls to have three or four days' herborising, and I found my host—the pilot of the cataracts—engaged in the festivities, which neither he nor my man would leave until the last drop of caulm (coarse cane or plantain spirit) was consumed. During the two days the feast lasted I was nearly famished, for, although there was food, nobody would cook it, and the guests sustained themselves entirely on caulm and ipadú. At short intervals ipadú

[1] See Mr. Cook's paper entitled "Staircase Farms of the Ancients" in The National Geographic Magazine, 29: 474–534. May, 1916.

was handed around in a large calabash with a tablespoon for each to help himself, the customary dose being a couple of spoonfuls. After each dose they passed some minutes without opening their mouths, adjusting the ipadû in the recesses of their cheeks and inhaling its delightful influences. I could scarcely resist laughing at their swollen cheeks and grave looks during these intervals of silence, which, however, had two or three times the excellent effect of checking an incipient quarrel. The ipadû is not sucked, but allowed to find its way insensibly into the stomach along with the saliva. I tried a spoonful twice, but it had little effect on me and assuredly did not render me insensible to the calls of hunger, although it did in some measure to those of sleep. It had very little of either smell or taste, and in both reminded me of weak tincture of henbane. I could never make out that the habitual use of ipadû had any ill results on the Rio Negro; but in Peru its excessive use is said to seriously injure the coats of the stomach, an effect probably owing to the lime taken along with it.

AYA-HUASCA, OR DEAD MAN'S VINE, BANISTERIA CAAPI.

Richard Spruce, in his Notes of a Botanist on the Amazon and Andes, describes a remarkable narcotic plant, the botanical identity of which he was the first to discover. It proved to belong to the genus Banisteria, and it is the only member of the family Malpighiaceae thus far known to possess narcotic properties. For its specific name he adopted the common name by which it was known in Brazil and Venezuela, caapi, signifying in the Tupi language "thin leaf."

Banisteria Caapi Spruce has a twining habit of growth. It has thinnish opposite leaves with oval-acuminate blades 6.4 by 3.3 inches in size with petioles scarcely an inch long. Its inflorescence is in the form of 4-flowered umbels. The flowers are composed of a 5-parted calyx and 5-clawed petals, 10 stamens, and 3 styles. The capsules are "muricato-cristate, prolonged on one side into a greenish white semi-obovate wing."

The lower part of the stem is beaten in a mortar with water, sometimes with the addition of a few slender roots of the *caapi-pinima*, an Apocynaceous twiner with red-veined leaves belonging to the genus Haemadictyon. When sufficiently triturated it is strained and enough water is added to it to make it drinkable. It forms a brownish-green infusion with a disagreeable bitter taste.

Mr. Spruce describes the ceremonial drinking of caapi at a feast held at a village above the first falls of the Rio Uaupés. It is accompanied by the greatest solemnity, and is preceded by the sound of the botutos, or sacred trumpets. On hearing these every woman seeks seclusion in a house with all possible haste; for merely to see one of these sacred instruments would be to her a sentence of death. The night was spent in dancing. Between the dances the young men partook of the drink, a few at a time. The formality attending the dispensing of it recalls that of the "black drink" ceremony of

our southeastern Indians, and the same is true of the taboos imposed upon the women, who were not permitted to touch or taste either the caapi here described or the black drink of our southeastern Indians, which will be described below.

In presenting the caapi the cupbearer runs quickly from the opposite end of the house with a small calabash containing about a teacupful in each hand, muttering "Mo-mo-mo-mo-mo" as he runs, and gradually sinking down until his chin nearly touches his knees, he presents one of the cups and then the other to the man for whom it is intended.

In two minutes or less after drinking it, its effects begin to be apparent. The Indian turns deadly pale, trembles in every limb, and horror is in his aspect. Suddenly contrary symptoms succeed; he bursts into a perspiration, and seems possessed with a reckless fury, seizes whatever arms are at hand, his murucú, bow and arrows, or cutlass, and rushes to the doorway, where he inflicts violent blows on the ground or the doorposts, calling out all the while, "Thus would I do to mine enemy (naming him by his name) were this he!" In about 10 minutes the excitement has passed off and the Indian grows calm, but appears exhausted. Were he at home in his hut he would sleep off the remaining fumes, but now he must shake off his drowsiness by renewing the dance.[1]

Spruce afterwards witnessed the use of this plant by the Indians inhabitating the northeastern Andes of Peru, and saw the plant itself growing in the villages of Canelos and Puca-yacu, inhabited chiefly by the Zaparos. Here it was called by the Quichua name Aya-huasca, which signifies "Dead man's vine." The following is a summary of what he learned concerning it at Puca-yacu:

Aya-huasca is used by the Zaparos, Angutéros, Mazánes, and other tribes precisely as I saw caapi used on the Uaupés, viz, as a narcotic stimulant at their feasts. It is also drunk by the medicine man, when called on to adjudicate in a dispute or quarrel, to give the proper answer to an embassy, to discover the plants of an enemy, to tell if strangers are coming, to ascertain if wives are unfaithful, in the case of a sick man to tell who has bewitched him, etc.

All who have partaken of it feel first vertigo, then as if they rose up into air and were floating about. The Indians say they see beautiful lakes, woods laden with fruit, birds of brilliant plumage, etc. Soon the scene changes; they see savage beasts preparing to seize them; they can no longer hold themselves up, but fall to the ground. At this crisis the Indian wakes up from his trance, and if he were not held down in his hammock by force, he would spring to his feet, seize his arms, and attack the first person who stood in his way. Then he becomes drowsy, and finally sleeps. If he be a medicine man who has taken it, when he has slept off the fumes he recalls all he saw in his trance, and thereupon deduces the prophecy, divination, or what not required of him. Boys are not allowed to taste aya-huasca before they reach puberty, nor women at any age, precisely as on the Uaupés.

[1] Richard Spruce. Notes of a Botanist on the Amazon and Andes, 2: 419–420. 1908.

Villavicencio says (in his Geografía de la Republica del Ecuador, p. 373, 1858):

When I have partaken of aya-huasca, my head has immediately begun to swim; then I have seemed to enter on an aerial voyage, wherein I thought I saw the most charming landscapes, great cities, lofty towers, beautiful parks, and other delightful things. Then all at once I found myself deserted in a forest and attacked by beasts of prey, against which I tried to defend myself. Lastly, I began to come round, but with a feeling of excessive drowsiness, headache, and sometimes general malaise.

This is all I have seen and learned of caapi or aya-huasca. I regret being unable to tell what is the peculiar narcotic principle that produces such extraordinary effects. Opium and hemp are its most obvious analogues, but caapi would seem to operate on the nervous system far more rapidly and violently than either. Some traveler who may follow my steps with greater resources at his command will, it is to be hoped, be able to bring away materials adequate for the complete analysis of this curious plant.[1]

In the above account the description of the hallucinations caused by the narcotic caapi, or aya-huasca, a remarkable parallel will be found with similar effects of *Lophophora Williamsii*, the narcotic cactus of the Aztecs already described.

ILEX TEAS.

Among the important stimulants, or restoratives, of ancient America were tea-like infusions and decoctions prepared from several species of holly, or ilex—in southern Brazil and Paraguay, from *Ilex paraguariensis*, commonly known as yerba mate; in Eucador, an ilex with much larger leaves, called guayusa; and in Florida, the Carolinas, and Texas, *Ilex vomitoria*, called cassine or yaupon, the scource of the celebrated ceremonial "black drink." All of these owe their stimulating virtues to an alkaloid, which has been identified with caffein. Prepared as a simple infusion by pouring hot water on the leaves, as in brewing the yerba mate, the effect is very much like tea itself. When boiled for a long time, as is the custom with the guayusa and cassine, the decoction has the effect of an emetic. It is interesting to note that in localities so widely remote as Ecuador and Florida the aboriginal inhabitants habitually used decoctions of ilex as an emetic and believed themselves benefited by vomiting. That the stimulating properties of two very closely allied plants like *Ilex paraguariensis* and *I. vomitoria* should have been independently discovered by tribes so widely separated as the Guaranis of South America and the Creeks of Florida is also remarkable, and especially in view of the fact that the leaves of the plants in question were subjected by the natives to a similar preliminary process of scorching before they were used. Another noteworthy feature connected with the black drink is the taboo imposed upon women by various tribes

[1] Spruce, op. cit., p. 424–425.

of the southern United States in connection with its ritual, which has remarkable parallels in the customs of various South American tribes in connection with their rituals accompanying the preparation and use of certain narcotics.

ILEX PARAGUARIENSIS, THE YERBA MATE OF PARAGUAY.

The use of the leaves of *Ilex paraguariensis* by the Guarani Indians and their neighbors must have begun centuries before the discovery. In pre-Columbian times the plant was known only in its wild state, but after the arrival of the Jesuits its cultivation was successfully undertaken in their missions in Paraguay and Brazil. When they were expelled the plantations went to ruin, but the industry was resumed at a later date and is now of great commercial importance. According to a bulletin of the Pan American Union issued in May, 1916, the value of the prepared leaves exported from Brazil amounts annually to about $8,727,000. In 1915 Argentina received from Brazil about 48,000 tons and 3,500 tons from Paraguay. The plantations of Paraguay were formerly guarded with jealous care. Bonpland, the companion of Humboldt, was imprisoned for many years by the Paraguayan Government for attempting to export living plants and seeds from Paraguay to Europe. For the methods of propagating, cultivating, gathering, curing, and packing yerba mate the reader is referred to the Pan American bulletin cited above.

The writer first encountered the custom of drinking Paraguay Tea in Uruguay, on an expedition with the eminent botanist, Don José Arechavaleta and his botany class of the National College of Medicine, October 1, 1886. The locality visited was an estancia, or cattle ranch, not far from the railway station of Santa Lucia. He recalls with pleasure the band of young students, many of them wearing the picturesque costume of the gauchos, or cowboys of the pampas—ponchos of guanaco wool, broad-brimmed hats, knives thrust in embossed silver scabbards, and silver spurs. At the station horses were awaiting many of them with silver-mounted bridles and saddles with heavy silver stirrups. After filling portfolios of drying paper with the beautiful spring flowers of the pampa (there were acres and acres of scarlet verbenas) yerba mate was served in gourds (*Cucurbita lagenaria*). These gourds, called mate, or mati in the Quichua language, give to the plant its name. The infusion was sucked up scalding hot through a bombilla, a silver tube terminating at the lower end in a hollow perforated bulb, which served as a strainer. A single gourd was passed around a circle composed of gauchos and students, each taking a suck at the bombilla in turn. To have hesitated to follow their example would have caused resentment. The infusion was not unlike tea, but more astringent, and too bitter for

the taste of a novice. Its effects were undoubtedly stimulating, very much like strong tea. During a continuation of his cruise the writer encountered yerba mate at Punta Arenas, on the Strait of Magellan, and at various ports along the coast of Chile; and later he found it offered for sale in the markets of Bolivia.[1]

Ilex paraguariensis is an evergreen shrub or small tree with short, petioled, glossy, oblong leaves 15 to 20 cm. long, acute or rounded at the apex and wedge shaped at the base, with the margin remotely toothed. The inflorescence consists of clusters of small flowers growing from the leaf axils. The small globose fruits usually contain four hard nutlets. The plant grows in Paraguay, especially at Villa Real, above Asuncion, and at Villa San Xavier, between the Rivers Uruguay and Parana. In Brazil the principal localities in which it is cultivated are in the State of Parana, Santa Catharina, and Rio Grande do Sul. The prepared yerba differs in quality. The more common kind, called guazu, is produced by pounding the scorched leaves in mortars in the earth. In preparing a finer grade, called caa mirim, the leaves are carefully chosen and deprived of their midrib before roasting, and the caa-cuys of Paraguay, the finest of all, is prepared from the scarcely expanded buds and young leaves.

THE GUAYUSA ILEX OF ECUADOR.

An Ilex resembling the yerba mate, but having much larger leaves, was found by Richard Spruce in Ecuador, where it was used by the Zaparo and Jibaro Indians inhabiting the eastern side of the equatorial Andes. It was called by them guayusa. Spruce could not satisfy himself as to its specific identity, for he was unable to secure either flowers or fruits for comparison with herbarium material. Botanists have not all agreed as to the delimitations of the various species of South American Ilex. Some have treated various forms, distinguished by the size of the leaves and other differences, as varieties of a single species; others have regarded them as botanically distinct. According to Miers several distinct species are used as a source of tea, including *Ilex curitibensis*, *I. gigantea*, *I. ovalifolia*, *I. humboldtiana*, and *I. nigropunctata*. The genus needs further critical study.

Spruce found the guayusa planted near villages and on the sites of abandoned settlements, at elevations as great as 5,000 feet above sea-level. In 1857 he observed a group of these trees in the gorge of the Rio Pastaza, below the town of Baños, which were supposed to have been planted before the conquest. He describes them as "not

[1] See Safford, W. E. "The flora of Banda Oriental." Bull. Torrey Botanical Club, 14: 159–164. 1887.

unlike old holly trees in England, except that the shining leaves were much larger, thinner, and unarmed." During his travels he found guayusa leaves to be a good substitute for tea or coffee. As prepared by the Jibaros Indians, however, the infusion is so strong that, like the black drink of our own Indians, it acts as an emetic. The guayusa pot, carefully covered up (like the pots in which the black drink was brewed), was kept simmering on the fire throughout the night. On awakening in the morning the Indian would drink enough of the guayusa to make him vomit, his notion being he would be benefited by the operation.[1] It is interesting to note that many Indian tribes both of North and South America practiced certain ceremonies attended by purging or vomiting, believing that thereby they would be freed from evil.

THE BLACK DRINK OF FLORIDA AND THE CAROLINAS.

(Plates 14 and 15.)

Ilex vomitoria takes its specific name from the emetic effect of its concentrated infusion, which under the common name of "black drink" was used ceremonially by several tribes of our southern Indians. Mark Catesby, in his Hortus americanus (1763) speaks of it as follows:

> The esteem the American Indians have for this shrub, from the great use they make of it, renders it most worthy of notice. They say its virtues have been known among them from the earliest times, and they have long used it in the same manner as they do at present. They prepare the leaves for keeping by drying or rather parching them in a pottage pot over a slow fire, and a strong decoction of the leaves thus cured is their beloved liquor, of which they drink large quantities, both for health and pleasure, without sugar or other mixture. They drink it down and disgorge it with ease, repeating it very often and swallowing many quarts. They say it restores lost appetite, strengthens the stomach, and confirms their health, giving them agility and courage in war. It grows chiefly in the maritime parts of the country, but not farther north than the capes of Virginia. The Indians of the seacoast supply those of the mountains therewith and carry on a considerable trade with it in Florida, just as the Spaniards do with their South Sea tea from Paraguay to Buenos Aires. Now, Florida being in the same latitude north as Paraguay is south, and no apparent difference being found on comparing the leaves of these two plants together, it is not improbable they may both be the same.
>
> In South Carolina it is called cassena, in Virginia and North Carolina it is known by the name of yopon; in the latter of which places it is as much in use among the white people as among the Indians, and especially among those who inhabit the seacoast.

The earliest written account of the ceremonial use of *Ilex vomitoria* is contained in the narrative of the expedition of Cabeza de Vaca, who found it in use among the Cultachiches (1536), west of

[1] Spruce, Richard. Notes of a Botanist on the Amazon and Andes, 2: 453. 1908.

the mouth of the Mississippi River. He described the plant as having leaves resembling those of an encina, or live oak. Its leaves, after having been toasted over the fire in an earthenware vessel were boiled for a long time, and the decoction poured into a vessel made of a half-gourd and stirred so as to make it foam. It was drunk boiling hot. While on the fire the vessel in which it was boiling was kept carefully covered;

and if by chance it should be uncovered, and a woman should come by in the meantime, they would drink none of it but fling it all away. Likewise while it was cooling and being poured out to drink, no woman was allowed to stir or make a motion, or they would pour it all out on the ground and spew up any which they might have drunk, while she would be severely beaten. All this time they would continue bawling out: "Who will drink?" whereupon the women, on hearing this call, became motionless, and were they sitting or standing, even on tip-toe, or with one leg raised and the other down, they dared not change their position until the men had cooled the liquor and made it ready to drink. The reason they gave for this is quite as foolish and unreasonable as the custom itself; for they said that if the women did not stand still on hearing the call some evil would be imparted to the liquor which they believed would make them die.

René de Laudonnière, the leader of the ill-fated Huguenot expedition to Florida (1564), noticed the use of the "black drink" as practiced by the Indians living at the mouth of the St. Johns River, Florida. Le Moine, his historian, wrote a narrative of the expedition, in which he mentions *cassine* leaves among the presents bestowed by the Indians upon the Frenchmen. Of the ceremonies accompanying its preparation and dispensing he gives the following account, accompanied by an illustration which is here reproduced (pl. 14). Unlike the Indians observed by Cabeza de Vaca, the Florida Indians did not exclude women from the ceremonies connected with its preparation, although neither they nor youths uninitiated into the dignity of manhood were permitted to partake of it.

The chief and his nobles are accustomed during certain days of the year to meet early every morning for this express purpose in a public place, in which a long bench is constructed, having at the middle of it a projecting part laid with nine round trunks of trees for the chief's seat. On this he sits by himself for distinction sake; and the rest come to salute him, one at a time, the oldest first, by lifting both hands twice to the height of the head and saying, "Ha, he, ya, ha, ha." To this the rest answer, "Ha, ha." Each as he completes his salutation takes his seat on the bench. If any question of importance is to be discussed the chief calls upon his Iauas (that is, his priests), and upon the elders, one at a time, to deliver their opinions. They decide upon nothing until they have held a number of councils over it, and they deliberate very sagely before deciding. Meanwhile the chief orders the women to boil some cassine, which is a drink prepared from the leaves from a certain root and which they afterwards pass through a strainer.

The chief and his councilors being now seated in their places, one stands before him, and spreading forth his hands wide open, asks a blessing upon the chief and the others who are to drink. Then the cupbearer brings the

hot drink in a capacious shell, first to the chief, and then, as the chief directs, to the rest in their order in the same shell. They esteem this drink so highly that no one is allowed to drink it in council unless he has proved himself a brave warrior. Moreover, this drink has the quality of at once throwing into a sweat whoever drinks it. On this account those who can not keep it down, but whose stomachs reject it are not intrusted with any difficult commission or any military responsibility, being considered unfit, for they often have to go three or four days without food; but one who can drink this liquor can go for 24 hours afterward without eating or drinking. In military expeditions also the only supplies which they carry consist of gourd bottles or wooden vessels full of this drink. It strengthens and nourishes the body and yet does not fly to the head as we have observed on occasion of these feasts of theirs.

Accounts of the Black Drink ceremony are given by many other writers, including John Lawson, in his History of Carolina (1714); James Adair, in his History of the American Indians (1775); Bossu, in his account of the Allibama Indians; Bernard Romans, in his Natural History of Florida (1775); and William Bartram, in his Travels in Florida (1791).[1]

By the Catawba Indians this plant was called yaupon; by the Creeks it was known as assi-luputski, or "small leaves," which literally corresponds to the Guarani name (caa-mirim) of the finer form of *Ilex paraguariensis*, a most interesting coincidence.

The custom of drinking tea made of *Ilex vomitoria* was adopted by many of the white settlers of Florida, the Carolinas and Georgia, but it has not persisted. Similar drinks are still used by certain tribes of Oklahoma, in the ceremonies connected with their feast commonly called the busk. According to the statements of various authors Ilex leaves alone were used along the southeastern seacoast, but in other localities it is quite probable that other plants were added to or substituted for the infusion, especially the so-called Indian tobacco, *Lobelia inflata*, and the button snake root, *Eryngium aquaticum*, both of which were held in high esteem by many tribes of North American Indians.

Ilex vomitoria (pl. 15) is an evergreen shrub or small tree. Its small glossy leaves, likened by Cabeza de Vace to those of an encina or live oak, and by Lawson to box leaves, are deep green above and pale beneath, oblong, oval, or elliptical in form, and obtuse at the apex, with the margins crenate-serrate. Those of the upper branches are 1 to 2.5 cm. long, while those on the vegetative shoots are often larger and oblong-lanceolate in shape. Though this species has been confused with *Ilex Cassine* L. by several botanists the two species are easily distinguished by their leaves. Those of *Ilex Cassine* are usually much larger, more nearly resembling those of *I. paraguariensis*, but with the margins entire or few toothed. The small

[1] See Hale, E. M., Bull. No. 14, Div. Bot., U. S. Dept. Agr. 1891.

white flowers of *Ilex vomitoria* are borne in axillary clusters having short smooth peduncles, and its flowers are distinguished from those of the allied species in having obtuse instead of acute calyx-teeth. In the pistillate flowers the 4 stamens are shorter than the petals, while in the staminate they are longer. The fruit is in the form of red globose drupes 5 or 6 mm. in diameter, usually containing 4 slightly ribbed nutlets. Plate 15 is the photograph of a specimen collected near Austin, Tex., May 27, 1904, by Mr. F. V. Coville, Botanist of the Bureau of Plant Industry.

GUARANÁ.

Guaraná is a substance somewhat resembling chocolate prepared from the bitter seeds of a Sapindaceous climber by certain tribes of Indians of Brazil and Venezuela. It owes its stimulating virtue to an alkaloid (guaranin) chemically allied to caffein. Like chocolate it is reputed to have aphrodisiac properties. In Venezuela it is known by the name of cupana. Although the plant from which it is derived is known as *Paullinia sorbilis*, a name applied to it by Martius, Spruce has shown that it is identical with the previously described *Paullinia cupana* of Humboldt, Bonpland and Kunth and that according to the rules of priority the latter name takes precedence.

Though normally a twining plant it is kept pruned in cultivation to the size of a currant bush. It has pinnate alternate leaves composed of 5 coarsely serrate leaflets, with the apical tooth retuse. The inflorescence consists of clusters of small white flowers growing in racemes from the axils of the leaves. The fruiting capsules are obovate to pyriform tapering at the base to a long neck or stipe and shortly beaked at the apex. When fresh they are yellow and tinged with red near the apex, with the thin pericarp smooth on the outside and woolly on the inner surface, 3-valved, but dehiscing only along two of the sutures. The solitary black glossy seed is nearly half covered by a white cup-shaped aril.

Martius gives a description of the process of making guaraná from the seeds of this plant by the Indians of the Rio Mauhé, Brazil. As prepared by them it is a very hard paste of a chocolate brown color almost devoid of odor. For use this paste is reduced to a fine powder and mixed with sugar and water to make a stimulating drink. The seeds, which mature in October and November, are removed from the capsules and dried in the sun until the fleshy white cups are in such a state as to be easily rubbed off with the fingers. They are then poured into a heated stone mortar, where they undergo a process of parching and are ground to a fine powder, which is mixed with water or exposed to the night dew and kneaded into a paste. When the process is finished a few seeds either whole or broken into fragments

are introduced and the whole is made up into sticks or cakes, usually cylindrical or spindle-shaped, about 5 to 8 inches long and weighing about 12 to 15 ounces. These sticks are then dried in the sun or by the fire and become so hard and resistant that it requires an axe to break them. They are then packed in broad leaves of banana-like plants and put into baskets or bags. If protected from moisture this paste will keep in good condition for several years. In the Province of Pará the jawbone of a fish called Piracurú, covered with sharp processes, is used as a rasp for grating it.

Humboldt and Bonpland state that in southern Venezuela the powdered seeds are mixed with mandioca flour, wrapped in plantain leaves, and allowed to ferment until it acquires a saffron-yellow color. This yellow paste, dried in the sun and diluted with water, is taken as a morning drink like tea or coffee. It is bitter, stimulating and tonic in its effects. Humboldt did not like its flavor, but Spruce, who drank it in the form of a cooling beverage prepared from the pure paste with cold water and sugar, liked its flavor and found that its effects were very much like those of tea. At Cuyabá it was served in taverns as a refreshing drink, and in various parts of South America Spruce found it to be a popular remedy for sick headache (hemicrania).[1]

CHOCOLATE.

(Plates 16 and 17.)

Chocolate, made from the seeds of *Theobroma cacao*, is undoubtedly of Central American origin. It was known to the inhabitants of Mexico and Central America long before the Discovery, and after the Conquest it soon found its way to Europe and to the most remote parts of the earth. No vestiges of the seeds or pods of cacao or any representation of them on funeral vases have been found in the prehistoric graves of the Peruvian coast region; and so rich are these graves in remains of fruits and vegetables as well as in representations of such objects in terra cotta that the inference is that cacao was unknown to the aboriginal inhabitants of that part of the world. Prescott's imaginary picture of the Peruvian coast adorned with plantations of cacao is wholly without foundation in fact.

Padre Cobo, in his Historia del Nuevo Mundo, tells of the high esteem in which cacao was held in Mexico:

> This fruit is so highly prized by the Indians of Nueva España that it serves for money in that kingdom, and with it they buy in the markets and from traveling venders small objects, such as tortillas of maize, fruits, and vegetables; and I on the roads of that kingdom bought such things many times with cacao. Even in the city of Mexico they give as alms to the poor Indians two or three cacaos, as though they were money.
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> But the reason why these cacao-almonds are principally esteemed is for a drink called chocolate, which the Indians made of them and which now the

[1] Spruce, Richard. Notes of a Botanist on the Amazon and Andes, 2: 448–453. 1908.

Spaniards prepare with greater neatness, care, and expense. It is of a dark-red color, with a foam which rises like scum and which is distasteful to newly arrived colonists and to those unaccustomed to drink it; but the people of the country are crazy for it. They regard chocolate as a delicacy, and Indians and Spaniards entertain with it the friends who come to their houses. In addition to the toasted and ground cacao seeds chocolate may contain many other ingredients, every one mixing with it those things which they fancy will improve its quality or flavor. But everybody usually puts in these five constituents: cacao, achiote (*Bixa orellana*), vanilla [the fruiting pod of an orchid called tlilxochitl, or "black flower," by the Aztecs], cinnamon [brought from the East Indies after the Discovery], and sugar [also an introduced product]. To these they add some other kinds of dried flowers [orejuela, or ear-flower, called xochinacaztli by the Aztecs], sesame, anise, chilli or ají (Capsicum pepper), and other things more or less according to their taste. In some parts of Central America (especially in Nicaragua) they make use of a preparation of ground cacao mixed with toasted and ground maize, which when mixed with water yields a delightful and nutritious drink called tiste * * *. The most highly prized cacao in New Spain is that which is grown in the Province of Soconosco and in the diocese of Guatemala; and the largest is that of the diocese of Venezuela, or Caracas * * *. Just as the almonds of Chachapoyas have bats for enemies, so the cacao has monkeys, which are bred in the large trees which shelter it, and they devour as much as they can.[1]

Plate 16 is the photograph of a trunk of cacao growing near the village of Coahuila, in the State of Chiapas, southern Mexico, taken in January, 1907, by Mr. Guy N. Collins of the United States Department of Agriculture, showing the peculiar habit of fruiting of the tree. In this region the cultivation of cacao is more successful and lucrative than in any other part of tropical America visited by Mr. Collins. Plate 17, which shows a slightly reduced pod from the same tree, will give some idea of the enormous size of the pods. The seeds are seen enveloped in their soft fleshy white aril. At this locality the trees produce almost continuously from November to June, and during this interval the pods are gathered three times.

As soon as the seeds are removed from the pods they are washed by placing them in shallow baskets partly submerged in water and rubbing them against the bottom and sides of the baskets, forcing the pulp through the meshes. The seeds are then sun dried, the quicker the better, it is thought. This unfermented product would not command a high price in the European or American markets, but it is said that the Mexicans do not demand a fermented bean. * * * From a few miles below Pichucalco to within a few miles of San Juan the banks of the river are almost continuously lined with cacao plantations, a great part of which is shaded with rubber. * * * About 1,500 tons of cacao pass through San Juan annually, valued at about $1,250,000. In spite of the enormous amount of cacao produced in Mexico and an import duty of 30 cents per kilo, cacao is still imported from Guayaquil. In the fine cacao lands above San Juan the growing of this commodity is the most lucrative agricultural operation with which we are familiar.

[1] Padre Cobo. Historia del Nuevo Mundo, 2: 63–64, ed. Jiménez de la Espada, 1891.

The primitive custom of using cacao for currency still prevails in the State of Chiapas, especially in the city of Tuxtla and its vicinity.

A common expression for cheap articles in the market here is that they sell for so many a cinco. This originally meant 5 cacao beans; but to allow for the fluctuating value of the cacao, a cinco actually consists of from 2 to 5 seeds, but the ratio of exchange will be uniform throughout the market.

Mr. Collins found three distinct types of cacao at Tuxtla: Small plump beans from Tabasco; flatter beans that had been rolled in ashes from Quechula; and cacao pataxte, the seeds of *Theobroma bicolor*. The latter parched and ground are used together with maize for making a drink called "posol" (from pozolli, foaming). Another drink called "tascalate" (from tezcalli, one who grinds maize or some other substance on a stone metlatl) was composed of ground cacao mixed with ground parched corn and almonds. It was carried in the form of powder by travelers on long trips when there was little opportunity of obtaining food, and made into an agreeable and nourishing drink by the addition of sugar and water.[1]

BOTANICAL DESCRIPTION.

Theobroma cacao is a small tree with a bare stem which generally rises to a height of about 2 meters before branching and reaches a height of 5 or 6 meters. Sometimes, however, under good conditions of moisture, soil, and situation it grows higher. The tree is cauliflorous; that is, the flowers spring forth from the trunk and older branches. Leaves large, undivided, smooth, broad, pointed, and of a thin texture, of a reddish color and hanging limp from the branches when young, but soon turning green and becoming firm; flowers produced from adventitious buds under the bark, usually at the "eyes," or points marked by the scars of fallen leaves, small, growing in clusters or solitary, usually only one of a cluster developing into fruit; calyx 5-parted, often of a pinkish color; petals 5, yellowish, concave at the base and having a straplike appendage at the tip; stamens 10, united at the base into a cup, 5 without anthers and the other 5 alternating with them bearing 2 double-celled anthers each; style threadlike, terminating in a 5-cleft stigma; fruit somewhat like a cucumber in shape, 15 to 25 cm. long, yellow or reddish, longitudinally ribbed, the rind thick and warty, leathery and tough, not splitting when ripe, 5-celled, and containing many seeds in a soft butterlike pulp of a pleasant sweetish-acid flavor; seeds compressed, somewhat almond shaped, with a thin, pale, reddish brown, fragile skin or shell covering an oily, aromatic, bitter

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[1] The above information was derived from Mr. Collins's field notes. See his abridged report: "Notes on Southern Mexico," by G. N. Collins and C. B. Doyle, of the U. S. Department of Agriculture, in the National Geographic Magazine, March, 1911, pp. 301 to 320.

kernel, which consists mostly of the crumpled cotyledons. If taken from the pod the seed soon loses its vitality. It is consequently difficult to transport it to distant countries unless in a germinating condition or in ripe pods, which, if kept cool, will last 10 days or perhaps 2 weeks.

In gathering the pods care is taken to cut the stalks neatly half way between the pod and the tree, so as not to tear the bark, as is often done if the pod is removed by twisting; for it is in the bark at the base of the old stalk that adventitious buds issue which produce the ensuing crop. As a rule only one or two of the flowers in each cluster develop pods. In many countries seeds are usually subjected to a process of sweating or fermenting, by means of which the flavor is developed. Sometimes this process takes place in holes or trenches in the ground, after which the seeds are dried. Plantations of cacao were visited by the writer in the French Antilles, on the island of Trinidad, in the vicinity of Caracas, and near Guayaquil. From the latter place great quantities of cacao are exported. In Mexico he witnessed the preparation of chocolate by grinding the beans into a paste on a stone metlatl just as maize is ground for making tortillas; and on the Pacific coast of Central America he was regaled with delicious tiste made of ground cacao and parched maize and served in gourds (the fruit of *Crescentia cujete*). On the island of Guam, where cacao culture was introduced from Mexico, the Mexican metlatl is used. Here the beans, after having been carefully cleaned, are usually dried without fermentation and kept until required for use. They are then toasted like coffee, ground on the family metlatl, and made at once into chocolate. Chocolate made from newly toasted and ground beans is especially rich and aromatic. Sometimes more than is required for immediate use is prepared with the addition of a little flour or arrowroot, but without spices, and made into balls or lozenge-shaped disks large enough for a single cup of chocolate. Thus prepared it has a fine flavor and since none of the oil is removed it is very rich. The natives of the island scorn imported chocolate, declaring that it tastes like medicine.

It is interesting to note that the alkaloid theobromine, which is the active principle of cacao, is also found in cola, which plays almost as important a rôle in certain parts of Africa as cacao in tropical America. More interesting still is the fact that this is almost identical with the alkaloids found in *Paullinia cupana* and the American ilexes described in this paper, and in tea and coffee. But while the ilexes and tea and coffee are only stimulants, chocolate is both stimulant and food. Theobromine is now valued in medicine, especially for use as a diuretic. Its physiological effects are very similar to those of caffein.

SUMMARY.

1. The principal narcotic plants and stimulants of ancient America were tobacco, cohoba, the red bean, peyotl, ololiuhqui, jimson weed, huaca-cachu (a tree Datura), coca, aya-huasca, yerba-mate, cassine, guaraná, and cacao. Divine attributes were ascribed to them. They were used in divination, in medicine, and in ceremonials, and in many cases were carried by the Indians as safeguards or amulets to insure success in warfare and the chase.

2. Tobacco, the most important of these plants, is now extensively cultivated in both hemispheres and its use is world wide. The jimson weed (*Datura stramonium*) is now important as a source of atropine, and coca (*Erythroxylon Coca*) as the source of cocaine. The most important stimulants are the yerba-mate (*Ilex paraguariensis*) the leaves of which are known as Paraguay tea, and cacao (*Theobroma Cacao*), the seeds of which are made into chocolate and cocoa.

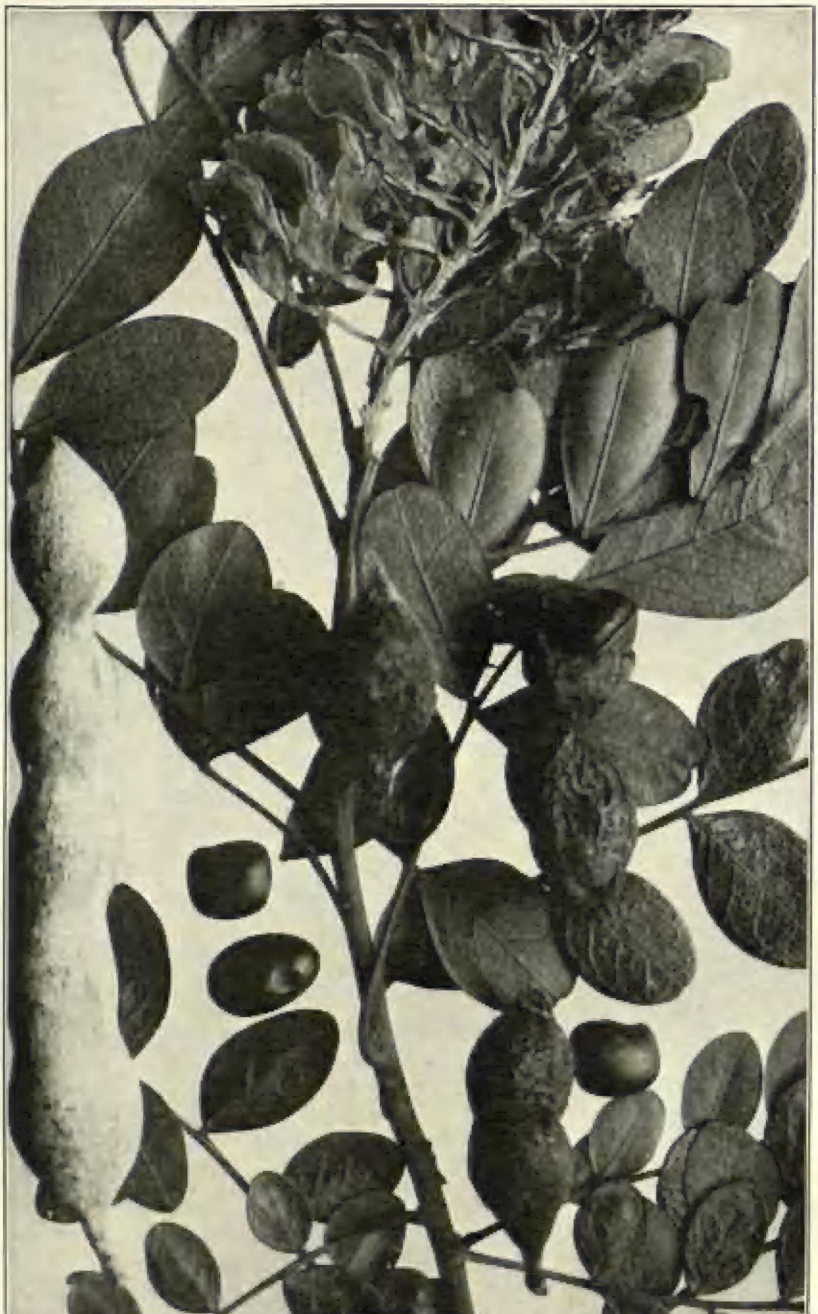
3. Of less importance but of possible medicinal value are peyotl (*Lophophora Williamsii*) identified as the "divine flesh" or teonanacatl of the Mexicans, and the ololiuhqui (*Datura meteloides*), still extensively used by Indians of Mexico and the United States; huaca-cachu (*Brugmansia sanguinea*) of Peru; and aya-huasca (*Banisteria caapi*) of Brazil and Venezuela. Cassine (*Ilex vomitoria*) of the southern United States, which has the same properties as its Paraguayan congener, may prove to be valuable as a refreshing tea, and guaraná (*Paullinia cupana*) as the source of a drink resembling chocolate. The red bean, or frijolillo, of Texas (*Broussonetia secundiflora*), though possessing a narcotic alkaloid, is not used commercially and its use among our Indians is now very limited. Cohoba (*Piptadenia peregrina*), the seeds of which were used by the aboriginal Haitians and are still used by many Indians of the tributaries of the great rivers of South America as the source of a narcotic snuff, remains chemically unknown, though known and reported by the companions of Columbus.

4. In view of the shortage of medicinal alkaloids resulting from the present war it is suggested that investigations be made to determine the nature of the properties of these less-known narcotics, with a view to their utilization as substitutes for others now recognized in the standard pharmacopœias.

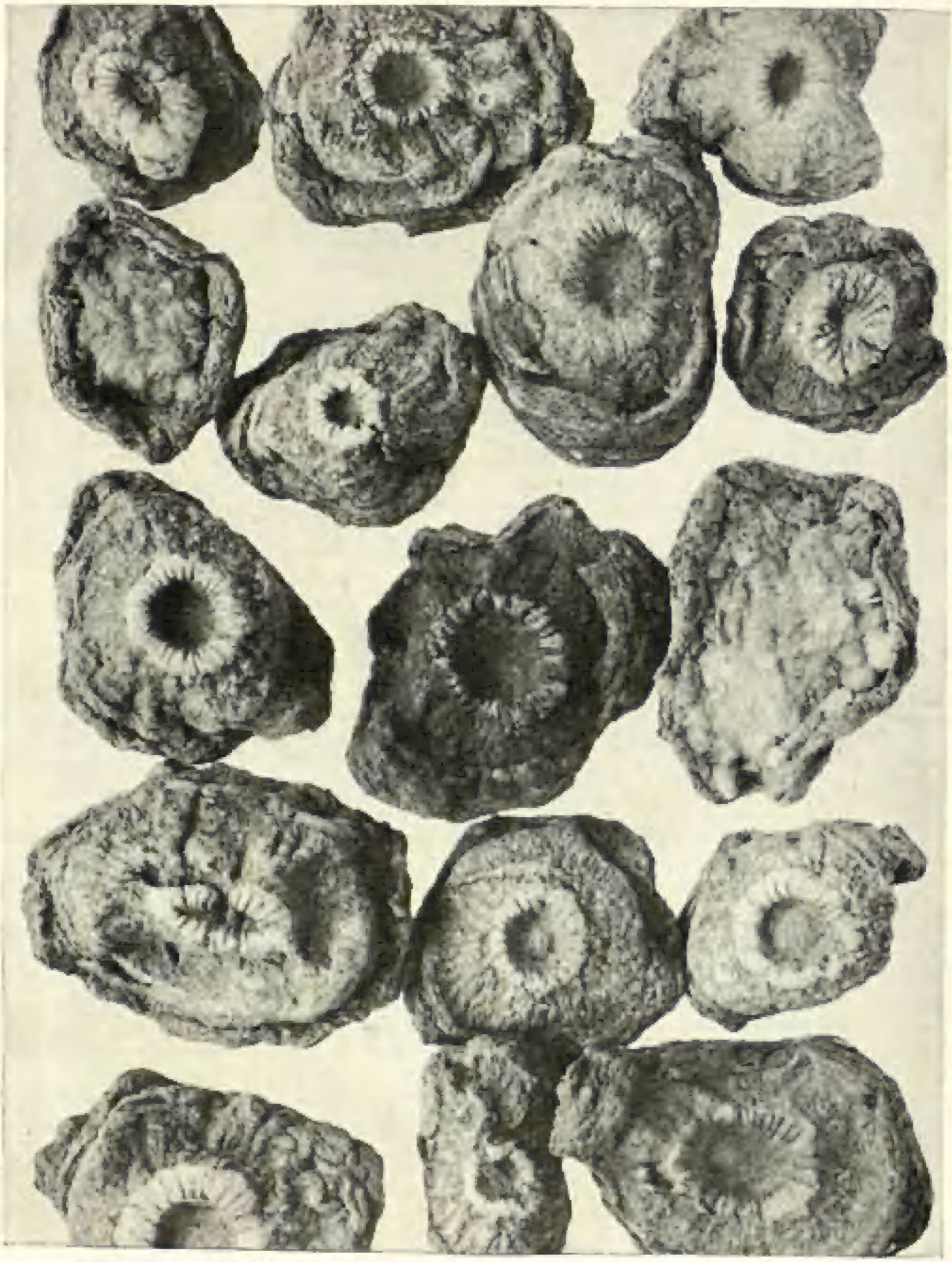
INFLORESCENCE OF NICOTIANA TABACUM, THE PICIETL OF MEXICO, THE PETUN OF BRAZIL.

NICOTIANA TABACUM: LEAF CHEWED BY THE ANCIENT MEXICANS TOGETHER WITH LIME, AND CALLED BY THEM TENEXIETL.

PIPTADENIA PEREGRINA, THE SOURCE OF THE NARCOTIC COHOBA SNUFF OF THE ANCIENT HAYTIANS. NATURAL SIZE.



BROUSSONETIA SECUNDIFLORA ORTEGA (SOPHORA SECUNDIFLORA LAG.); THE PLANT YIELDING THE NARCOTIC MESCAL BEAN OF NORTHERN MEXICO AND SOUTHWESTERN UNITED STATES.



DISKS OF LOPHOPHORA WILLIAMSII, CALLED "SACRED MUSHROOMS" (TEONANACATL) BY THE ANCIENT MEXICANS.

DEVIL'S ROOT (LOPHOPHORA WILLIAMSII).

LOPHOPHORA WILLIAMSII, A NARCOTIC CACTUS; THE PEYOTL, OR TEONANACATL, OF THE AZTECS.

Photographed by F. E. Lloyd in northern Zacatecas.

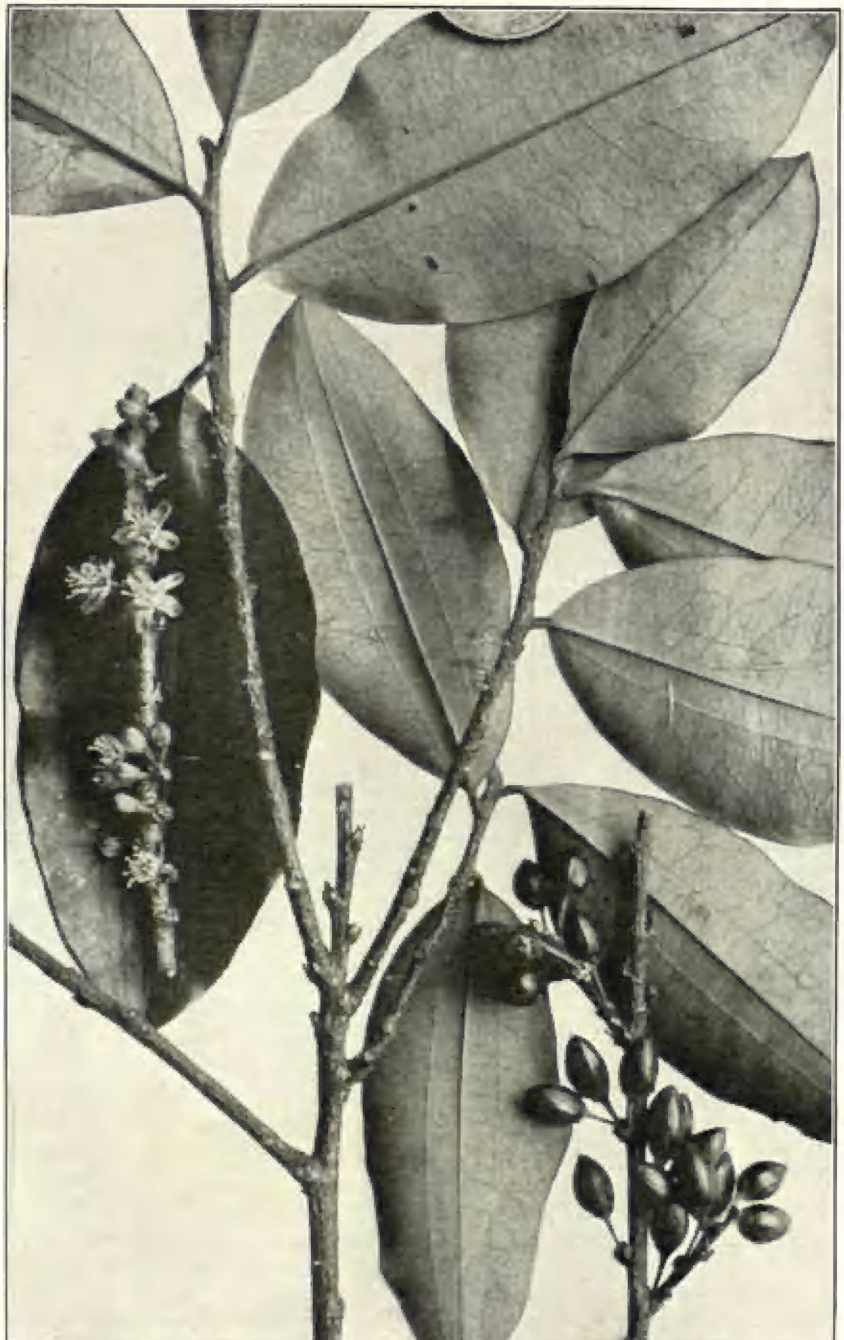
DATURA METELOIDES, A CEREMONIAL NARCOTIC OF THE ANCIENT MEXICANS, ZUÑIS, AND CALIFORNIA INDIANS. TWO-THIRDS NATURAL SIZE.

DATURA METELOIDES, NARCOTIC PLANT USED BY THE ANCIENT AZTECS, ZUÑIS, AND CALIFORNIA INDIANS AS AN INTOXICANT AND HYPNOTIC. NATURAL SIZE.

THE JAMESTOWN WEED, DATURA STRAMONIUM L., WHICH INTOXICATED THE BRITISH SOLDIERS SENT TO QUELL BACON'S REBELLION. NATURAL SIZE.

TREE DATURA (BRUGMANSIA SANGUINEA), USED AS A NARCOTIC BY THE PRIESTS OF THE TEMPLE OF THE SUN.

POUCH CONTAINING COCA LEAVES FROM PREHISTORIC PERUVIAN GRAVE, TOGETHER WITH GOURD CONTAINING LIME.

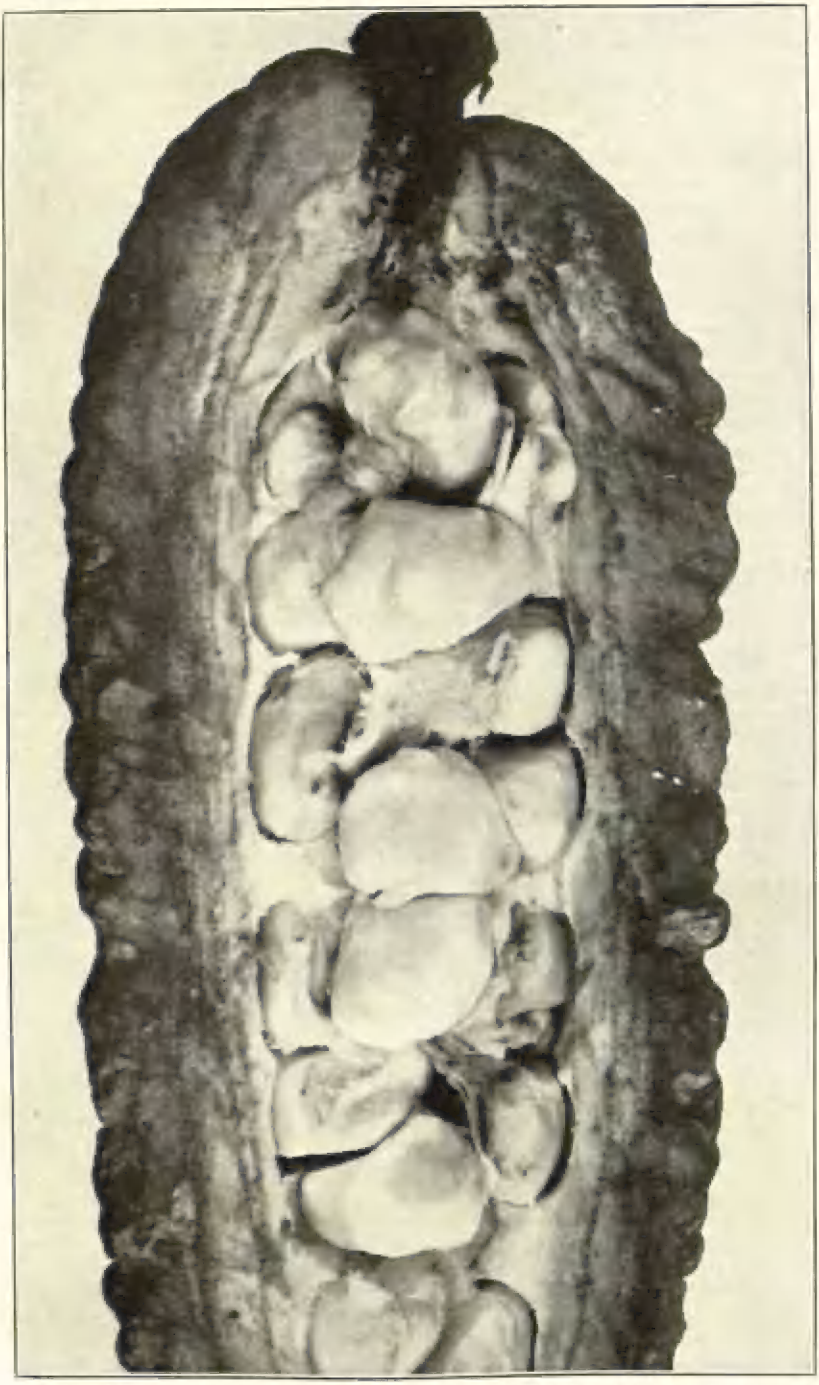


ERYTHROXYLON COCA, THE SOURCE OF COCAINE. PHOTOGRAPH OF SPECIMEN COLLECTED AT SANTA ANA, PERU, BY O. F. COOK.

BLACK DRINK CEREMONY AS PERFORMED IN NORTHERN FLORIDA, AFTER LE MOYNE (1564).

ILEX VOMITORIA, THE SOURCE OF THE BLACK DRINK OF THE INDIANS OF FLORIDA AND THE CAROLINAS. SPECIMEN COLLECTED NEAR AUSTIN, TEX., MAY 27, 1904, BY FREDERICK V. COVILLE. NATURAL SIZE.

THEOBROMA CACAO, THE PLANT FROM WHICH CACAO IS OBTAINED. SPECIMEN GROWING IN THE STATE OF CHIAPAS, MEXICO. PHOTOGRAPHED BY COLLINS AND DOYLE.



CACAO POD, SHOWING SEEDS SURROUNDED BY FLESHY WHITE ARIL. SPECIMEN FROM TREE SHOWN ON PRECEDING PLATE.

NEW ARCHEOLOGICAL LIGHTS ON THE ORIGINS OF CIVILIZATION IN EUROPE.[1]

By Sir Arthur Evans, D. Litt., LL. D., P. S. A., F. R. S.

When I was asked on behalf of the council of the British Association to occupy the responsible post of president at the meeting in this great city—the fourth that has taken place here—I was certainly taken by surprise; the more so as my own subject of research seemed somewhat removed from what may be described as the central interests of your body. The turn of archeology, however, I was told, had come round again on the rota of the sciences represented; nor could I be indifferent to the fact that the last presidential address on this theme had been delivered by my father at the Toronto meeting of 1897.

Still, it was not till after considerable hesitation that I accepted the honor. Engaged as I have been through a series of years in the work of excavation in Crete—a work which involved not only the quarrying but the building up of wholly new materials and has entailed the endeavor to classify the successive phases of a long, continuous story—absorbed and fascinated by my own investigation, I am oppressed with the consciousness of having been less able to keep pace with the progress of fellow explorers in other departments or to do sufficient justice to their results. * * * The science of antiquity in its purest form depends, indeed, on evidence and rests on principles indistinguishable from those of the sister science of geology. Its methods are stratigraphic. As in that case the successive deposits and the characteristic contents—often of the most fragmentary kind—enable the geologist to reconstruct the fauna and flora, and climate and physical conditions of the past ages of the world, and to follow out their gradual transitions or dislocations, so it is with the archeologist in dealing with unwritten history.

In recent years—not to speak of the revelations of late quaternary culture on which I shall presently have occasion to dwell—in Egypt, in Babylonia, in ancient Persia, in the central Asian deserts, or, coming nearer home, in the Ægean lands, the patient exploration

[1]Address of the president of the British Association for the Advancement of Science, Newcastle-on-Tyne, 1916. Reprinted by permission from author's pamphlet edition.

of early sites, in many cases of huge stratified mounds, the unearthing of buried buildings, the opening of tombs, and the research of minor relics, has reconstituted the successive stages of whole fabrics of former civilization, the very existence of which was formerly unsuspected. Even in later periods archeology, as a dispassionate witness, has been continually checking, supplementing, and illustrating written history. It has called back to our upper air, as with a magician's wand, shapes and conditions that seemed to have been irrevocably lost in the night of time.

Thus evoked, moreover, the past is often seen to hold a mirror to the future, correcting wrong impressions—the result of some temporary revolution in the whirligig of time—by the more permanent standard of abiding conditions, and affording in the solid evidence of past well-being the "substance of things hoped for." Nowhere, indeed, has this been more in evidence than in that vexed region between the Danube and the Adriatic, to-day the home of the Serbian race, to the antiquarian exploration of which many of the earlier years of my own life were devoted.

What visions, indeed, do those investigations not recall! Imperial cities, once the seats of wide administration and of prolific mints, sunk to neglected villages, vestiges of great engineering works, bridges, aqueducts, or here a main line of ancient highway hardly traceable even as a track across the wilderness! Or, again, the signs of medieval revival above the Roman ruins—remains of once populous mining centers scattered along the lone hillside, the shells of stately churches with the effigies, bullet-scarred now, of royal founders, once champions of Christendom against the Paynim—nay, the actual relics of great rulers, lawgivers, national heroes, still secreted in half-ruined monastic retreats! Sunt lacrimæ rerum et mentem mortalia tangunt. Even the archeologist incurs more human debts, and the evocation of the past carries with it living responsibilities. * * *

Whole provinces of ancient history would lie beyond our ken—often through the mere loss of the works of classical authors—were it not for the results of archeological research. At other times again it has redressed the balance where certain aspects of the ancient world have been brought into unequal prominence, it may be, by mere accidents of literary style. Even if we take the Greek world, generally so rich in its literary sources, how comparatively little should we know of its brilliant civilization as illustrated by the great civic foundations of Magna Graecia and Sicily if we had to depend on its written sources alone. But the noble monuments of those regions, the results of excavation, the magnificent coinage—a sum of evidence illustrative in turn of public and private life, of art and

religion, of politics and of economic conditions—have gone far to supply the lacuna.

Look, too, at the history of the Roman Empire—how defective and misleading in many departments are the literary records. It has been by methodical researches into evidence such as the above, notably in the epigraphic field, that the most trustworthy results have been worked out.

Take the case of Roman Britain. Had the lost books of Ammianus relating to Britain been preserved we might have had, in his rugged style, some partial sketch of the Province as it existed in the age of its most complete Romanization. As it is, so far as historians are concerned, we are left in almost complete darkness. Here, again, it is through archeological research that light has penetrated, and thanks to the thoroughness and persistence of our own investigators, town sites such as Silchester in Roman Britain have been more completely uncovered than those of any other Province.[1] Nor has any part of Britain supplied more important contributions in this field than the region of the Roman wall, that great limitary work between the Solway and the mouth of the Tyne that once marked the northernmost European barrier of civilized dominion.

Speaking here, on the site of Hadrian's bridge-head station that formed its eastern key, it would be impossible for me not to pay a passing tribute, however inadequate, to the continuous work of exploration and research carried out by the Society of Antiquaries of Newcastle, now for over a hundred years in existence, worthily seconded by its sister society on the Cumbrian side, and of which the volumes of the respective Proceedings and Transactions, Archæologia, Æliana, and last but not least the Lapidarium Septentrionale, are abiding records. The basis of methodical study was here the survey of the wall carried out, together with that of its main military approach, the Watling Street, by MacLauchlan, under the auspices of Algernon, fourth Duke of Northumberland. And who, however lightly touching on such a theme, can overlook the services of the late Dr. Collingwood Bruce, the "Grand old man," not only of the wall itself, but of all pertaining to border antiquities, distinguished as an investigator for his scholarship and learning, whose lifelong devotion to his subject and contagious enthusiasm made the Roman wall, as it had never been before, a household word?

New points of view have arisen, a stricter method and a greater subdivision of labor have become imperative in this as in other departments of research. We must, therefore, rejoice that local explorers have more and more availed themselves of the cooperation, and welcomed the guidance of those equipped with comparative knowl-

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[1] See Haverfield, "Roman Britain in 1913," p. 86.

edge drawn from other spheres. The British Vallum, it is now realized, must be looked at with perpetual reference to other frontier lines, such as the Germanic or the Rhaetian lines; local remains of every kind have to be correlated with similar discoveries throughout the length and breadth of the Roman Empire.

This attitude in the investigation of the remains of Roman Britain—the promotion of which owes so much to the energy and experience of Prof. Haverfield—has in recent years conducted excavation to specially valuable results. The work at Corbridge, the ancient Corstopitum, begun in 1906, and continued down to the autumn of 1914, has already uncovered throughout a great part of its area the largest urban center—civil as well as military in character—on the line of the wall, and the principal store base of its stations. Here, together with well-built granaries, workshops, and barracks, and such records of civic life as are supplied by sculptured stones and inscriptions, and the double discovery of hoards of gold coins, has come to light a spacious and massively constructed stone building, apparently a military storehouse, worthy to rank beside the bridge piers of the North Tyne, among the most imposing monuments of Roman Britain. There is much here, indeed, to carry our thoughts far beyond our insular limits. On this, as on so many other sites along the wall, the inscriptions and reliefs take us very far afield. We mark the gravestone of a man of Palmyra, an altar of the Tyrian Hercules—its Phoenician Baal—a dedication to a pantheistic goddess of Syrian religion and the rayed effigy of the Persian Mithra. So, too, in the neighborhood of Newcastle itself, as elsewhere on the wall, there was found an altar of Jupiter Dolichenus, the old Anatolian God of the Double Axe, the male form of the divinity once worshipped in the prehistoric Labyrinth of Crete. Nowhere are we more struck than in this remote extremity of the Empire with the heterogeneous religious elements, often drawn from its far eastern borders, that before the days of the final advent of Christianity, Roman dominion had been instrumental in diffusing. The Orontes may be said to have flowed into the Tyne as well as the Tiber.

I have no pretension to follow up the various affluents merged in the later course of Greco-Roman civilization, as illustrated by these and similar discoveries throughout the Roman world. My own recent researches have been particularly concerned with the much more ancient cultural stage—that of prehistoric Crete—which leads up to the Greco-Roman, and which might seem to present the problem of origins at any rate in a less complex shape. The marvelous Minoan civilization that has there come to light shows that Crete of 4,000 years ago must unquestionably be regarded as the birthplace of our European civilization in its higher form.

But are we, even then, appreciably nearer to the fountain head?

A new and far more remote vista has opened out in recent years, and it is not too much to say that a wholly new standpoint has been gained from which to survey the early history of the human race. The investigations of a brilliant band of prehistoric archeologists, with the aid of representatives of the sister sciences of geology and paleontology, have brought together such a mass of striking materials as to place the evolution of human art and appliances in the last Quaternary period on a far higher level than had even been suspected previously. Following in the footsteps of Lartet and after him Rivière and Piette, Profs. Cartailhac, Capitan, and Boule, the Abbé Breuil, Dr. Obermeier and their fellow investigators have revolutionized our knowledge of a phase of human culture which goes so far back beyond the limits of any continuous story that it may well be said to belong to an older world.

To the engraved and sculptured works of man in the "Reindeer period" we have now to add not only such new specialties as are exemplified by the molded clay figures of life-size bisons in the Tuc d'Audoubert Cave, or the similar high reliefs of a procession of six horses cut on the overhanging limestone brow of Cap Blanc, but whole galleries of painted designs on the walls of caverns and rock shelters.

So astonishing was this last discovery, made first by the Spanish investigator Señor de Sautuola—or rather his little daughter—as long ago as 1878, that it was not till after it had been corroborated by repeated finds on the French side of the Pyrenees—not, indeed, till the beginning of the present century—that the Paleolithic age of these rock paintings was generally recognized. In their most developed stage, as illustrated by the bulk of the figures in the Cave of Altamira itself, and in those of Marsoulas in the Haute Garonne, and of Font de Gaume in the Dordogne, these primeval frescoes display not only a consummate mastery of natural design, but an extraordinary technical resource. Apart from the charcoal used in certain outlines, the chief coloring matter was red and yellow ochre, mortars and palettes for the preparation of which have come to light. In single animals the tints are varied from black to dark and ruddy brown or brilliant orange, and so, by fine gradations, to paler nuances, obtained by scraping and washing. Outlines and details are brought out by white incised lines, and the artists availed themselves with great skill of the reliefs afforded by convexities of the rock surface. But the greatest marvel of all is that such polychrome masterpieces as the bisons, standing and couchant, or with limbs huddled together, of the Altamira Cave, were executed on the ceilings of inner vaults and galleries where the light of day has never penetrated. Nowhere

is there any trace of smoke, and it is clear that great progress in the art of artificial illumination had already been made. We now know that stone lamps, decorated in one case with the engraved head of an ibex, were already in existence.

Such was the level of artistic attainment in southwestern Europe, at a modest estimate some 10,000 years earlier than the most ancient monuments of Egypt or Chaldæa! Nor is this an isolated phenomenon. One by one, characteristics, both spiritual and material, that had been formerly thought to be the special marks of later ages of mankind have been shown to go back to that earlier world. I myself can never forget the impression produced on me as a privileged spectator of a freshly uncovered interment in one of the Balzi Rossi Caves—an impression subsequently confirmed by other experiences of similar discoveries in these caves, which together first supplied the concordant testimony of an elaborate cult of the dead on the part of Aurignacian man. Tall skeletons of the highly developed Cro-Magnon type lay beside or above their hearths, and protected by great stones from roving beasts. Flint knives and bone javelins had been placed within reach of their hands, chaplets and necklaces of sea shells, fish vertebræ, and studs of carved bone had decked their persons. With these had been set lumps of iron peroxide, the red stains of which appeared on skulls and bones, so that they might make a fitting show in the underworld.

> Colors, too, to paint his body,
>   Place within his hand,
> That he glisten, bright and ruddy,
>   In the Spirit-Land![1]

Nor is it only in this cult of the departed that we trace the dawn of religious practices in that older world. At Cogul we may now survey the ritual dance of nine skirted women round a male satyrlike figure of short stature, while at Alpera a gowned sister ministrant holds up what has all the appearance of being a small idol. It can hardly be doubted that the small female images of ivory, steatite, and crystalline talc from the same Aurignacian stratum as that of the Balzi Rossi interments, in which great prominence is given to the organs of maternity, had some fetichistic intention. So, too, many of the figures of animals engraved and painted on the inmost vaults of the caves may well have been due, as M. Salomon Reinach has suggested, to the magical ideas prompted by the desire to obtain a hold on the quarries of the chase that supplied the means of livelihood.

In a similar religious connection may be taken the growth of a whole family of signs, in some cases obviously derivatives of fuller pictorial originals, but not infrequently simplified to such a degree

[1] Schiller "Nadowessier's Todtenlied."

that they resemble or actually reproduce letters of the alphabet. Often they occur in groups like regular inscriptions, and it is not surprising that in some quarters they should have been regarded as evidence that the art of writing had already been evolved by the men of the Reindeer age. A symbolic value certainly is to be attributed to these signs, and it must at least be admitted that by the close of the late Quaternary age considerable advance had been made in hieroglyphic expression.

The evidences of more or less continuous civilized development reaching its apogee about the close of the Magdalenian period have been constantly emerging from recent discoveries. The recurring "tectiform" sign had already clearly pointed to the existence of huts or wigwams; the "scutiform" and other types record appliances yet to be elucidated, and another sign well illustrated on a bone pendant from the Cave of St. Marcel has an unmistakable resemblance to a sledge.[1] But the most astonishing revelation of the cultural level already reached by primeval man has been supplied by the more recently discovered rock paintings of Spain. The area of discovery has now been extended there from the Province of Santander, where Altamira itself is situated, to the Valley of the Ebro, the Central Sierras, and to the extreme southeastern region, including the Provinces of Albacete, Murcia, and Almeria, and even to within the borders of Granada.

One after another, features that had been reckoned as the exclusive property of Neolithic or later ages are thus seen to have been shared by Paleolithic man in the final stage of his evolution. For the first time, moreover, we find the productions of his art rich in human subjects. At Cogul the sacral dance is performed by women clad from the waist downward in well-cut gowns, while in a rock shelter of Alpera,[2] where we meet with the same skirted ladies, their dress is supplemented by flying sashes. On the rock painting of the Cueva de la Vieja, near the same place, women are seen with still longer gowns rising to their bosoms. We are already a long way from Eve.

It is this great Alpera fresco which, among all those discovered, has afforded most new elements. Here are depicted whole scenes of the chase in which bowmen—up to the time of these last discoveries unknown among Paleolithic representations—take a leading part, though they had not as yet the use of quivers. Some are dancing in the attitude of the Australian corroborees. Several wear plumed headdresses, and the attitudes at times are extraordinarily animated. What is specially remarkable is that some of the groups of these

[1] This interpretation suggested by me after inspecting the object in 1902 has been approved by the Abbé Breuil (Anthropologie, XIII, p. 152) and by Professor Sollas, "Ancient Hunters,"[2] 1915, p. 480.

[2] That of Carasoles del Bosque: Breuil, Anthropologie, XXVI, 1915, p. 329, et seq.

Spanish rock paintings show dogs or jackals accompanying the hunters, so that the process of domesticating animals had already begun. Hafted axes are depicted as well as cunningly shaped throwing sticks. In one case at least we see two opposed bands of archers—marking at any rate a stage in social development in which organized warfare was possible.

Nor can there be any question as to the age of these scenes and figures, by themselves so suggestive of a much later phase of human history. They are inseparable from other elements of the same group, the animal and symbolic representations of which are shared by the contemporary school of rock painting north of the Pyrenees. Some are overlaid by palimpsests, themselves of Paleolithic character. Among the animals actually depicted, moreover, the elk and bison distinctly belong to the late Quaternary fauna of both regions, and are unknown there to the Neolithic deposits.

In its broader aspects this field of human culture, to which, on the European side, the name of Reindeer age may still, on the whole, be applied, is now seen to have been very widespread. In Europe itself it permeates a large area—defined by the boundaries of glaciation—from Poland, and even a large Russian tract, to Bohemia, the upper course of the Danube and of the Rhine, to southwestern Britain and southeastern Spain. Beyond the Mediterranean, moreover, it fits on under varying conditions to a parallel form of culture, the remains of which are by no means confined to the Cis-Saharan zone, where incised figures occur of animals like the long-horned buffalo (*Bulbalus antiquus*) and others long extinct in that region. This southern branch may eventually be found to have a large extension. The nearest parallels to the finer class of rock carvings as seen in the Dordogne are, in fact, to be found among the more ancient specimens of similar work in South Africa, while the rock paintings of Spain find their best analogies among the Bushmen.

Glancing at this late Quaternary culture, as a whole, in view of the materials supplied on the European side, it will not be superfluous for me to call attention to two important points which some observers have shown a tendency to pass over.

Its successive phases, the Aurignacian, the Solutrean, and the Magdalenian, with its decadent Azilian offshoot—the order of which may now be regarded as stratigraphically established—represent, on the whole, a continuous story.

I will not here discuss the question as to how far the disappearance of Neanderthal man and the close of the Mousterian epoch represents a "fault" or gap. But the view that there was any real break in the course of the cultural history of the Reindeer age itself does not seem to have sufficient warrant.

It is true that new elements came in from more than one direction. On the old Aurignacian area, which had a trans-Mediterranean extension from Syria to Morocco, there intruded on the European side—apparently from the east—the Solutrean type of culture, with its perfected flint-working and exquisite laurel-leaf points. Magdalenian man, on the other hand, great as the proficiency that he attained in the carving of horn and bone, was much behind in his flint-knapping. That there were dislocations and temporary setbacks is evident. But on every side we still note transitions and reminiscences. When, moreover, we turn to the most striking features of this whole cultural phase, the primeval arts of sculpture, engraving, and painting, we see a gradual upgrowth and unbroken tradition. From mere outline figures and simple two-legged profiles of animals we are led on step by step to the full freedom of the Magdalenian artists. From isolated or disconnected subjects we watch the advance to large compositions, such as the hunting scenes of the Spanish rock paintings. In the culminating phase of this art we even find impressionist works. A brilliant illustration of such is seen in the galloping herds of horses, lightly sketched by the engraver on the stone slab from the Chaumont Grotto, depicting the leader in each case in front of his troop, and its serried line—straight as that of a well-drilled battalion—in perspective rendering. The whole must be taken to be a faithful memory sketch of an exciting episode of prairie life.

The other characteristic feature of the culture of the Reindeer age that seems to deserve special emphasis, and is almost the corollary of the foregoing, is that it can not be regarded as the property of a single race. It is true that the finely built Cro-Magnon race seems to have predominated, and must be regarded as an element of continuity throughout, but the evidences of the coexistence of other human types is clear. Of the physical characteristics of these it is not my province to speak. Here it will be sufficient to point out that their interments, as well as their general associations, conclusively show that they shared, even in its details, the common culture of the age, followed the same fashions, plied the same arts, and were imbued with the same beliefs as the Cro-Magnon folk. The negroid skeletons intercalated in the interesting succession of hearths and interments of the Grotte des Enfants at Grimaldi had been buried with the same rites, decked with the same shell ornaments, and were supplied with the same red coloring matter for use in the spirit world, as we find in the other sepultures of these caves belonging to the Cro-Magnon race. Similar burial rites were associated in this country with the "Red Lady of Paviland," the contemporary Aurignacian date of which is now well established. A like identity of

funeral custom recurred again in the sepulture of a man of the "Brünn" race on the eastern boundary of this field of culture.

In other words, the conditions prevailing were analogous to those of modern Europe. Cultural features of the same general character had imposed themselves on a heterogeneous population. That there was a considerable amount of circulation, indeed—if not of primitive commerce—among the peoples of the Reindeer age is shown by the diffusion of shell or fossil ornaments derived from the Atlantic, the Mediterranean, or from inland geological strata. Art itself is less the property of one or another race than has sometimes been imagined—indeed, if we compare those products of the modern carver's art that have most analogy with the horn and bone carvings of the cave men and rise at times to great excellence—as we see them, for instance, in Switzerland or Norway—they are often the work of races of very different physical types. The negroid contributions, at least in the southern zone of this late Quaternary field, must not be underestimated. The early steatopygous images—such as some of these of the Balzi Rossi caves—may safely be regarded as due to this ethnic type, which is also pictorially represented in some of the Spanish rock paintings.

The nascent flame of primeval culture was thus already kindled in that older world, and, so far as our present knowledge goes, it was in the southwestern part of our continent, on either side of the Pyrenees, that it shone its brightest. After the great strides in human progress already made at that remote epoch, it is hard, indeed, to understand what it was that still delayed the rise of European civilization in its higher shape. Yet it had to wait for its fulfillment through many millennia. The gathering shadows thickened and the darkness of a long night fell not on that favored region alone, but throughout the wide area where Reindeer man had ranged. Still the question rises—as yet imperfectly answered—were there no relay runners to pass on elsewhere the lighted torch?

Something, indeed, has been recently done toward bridging over the "hiatus" that formerly separated the Neolithic from the Paleolithic age—the yawning gulf between two worlds of human existence. The Azilian—a later decadent outgrowth of the preceding culture—which is now seen partially to fill the lacuna, seems to be in some respects an impoverished survival of the Aurignacian.[1] The existence of this phase was first established by the long and patient investigations of Piette in the stratified deposits of the cave of Mas d'Azil in the Ariège, from which it derives its name, and it has been proved by recent discoveries to have had a wide extension. It affords evidence of a milder and moister climate—well illustrated by

[1] Breuil, "Congr. Préhist.," Geneva, 1912, p. 216.

the abundance of the little wood snail (*Helix nemoralis*) and the increasing tendency of the reindeer to die out in the southern parts of the area, so that in the fabric of the characteristic harpoons deer-horns are used as substitutes. Artistic designs now fail us, but the polychrome technique of the preceding age still survives in certain schematic and geometric figures, and in curious colored signs on pebbles. These last first came to light in the cave of Mas d'Azil, but they have now been found to recur much further afield in a similar association in grottoes from the neighborhood of Basel to that of Salamanca. So like letters are some of these signs that the lively imagination of Piette saw in them the actual characters of a primeval alphabet.

The little flakes with a worked edge, often known as "pygmy flints," which were, most of them, designed for insertion into bone or horn harpoons, like some Neolithic examples, are very characteristic of this stratum, which is widely diffused in France and elsewhere under the misleading name of "Tardenoisian." At Ofnet, in Bavaria, it is associated with a ceremonial skull burial showing the coexistence at that spot of brachycephalic and dolichocephalic types, both of a new character. In Britain, as we know, this Azilian, or a closely allied phase, is traceable as far north as the Oban Caves.

What, however, is of special interest is the existence of a northern parallel to this cultural phase, first ascertained by the Danish investigator, Dr. Sarauw, in the lake station of Maglemose, near the west coast of Zealand. Here bone harpoons of the Azilian type occur, with bone and horn implements showing geometrical and rude animal engravings of a character divergent from the Magdalenian tradition. The settlement took place when what is now the Baltic was still the great "Ancylus Lake," and the waters of the North Sea had not yet burst into it. It belongs to the period of the Danish pine and birch woods and is shown to be anterior to the earliest shell mounds of the Kitchenmidden people, when the pine and the birch had given place to the oak. Similar deposits extend to Sweden and Norway and to the Baltic Provinces as far as the Gulf of Finland. The parallel relationship of this culture is clear, and its remains are often accompanied with the characteristic "pygmy" flints. Breuil, however,[1] while admitting the late Paleolithic character of this northern branch, would bring it into relation with a vast Siberian and Altaic province, distinguished by the widespread existence of rock carvings of animals. It is interesting to note that a rock engraving of a reindeer, very well stylized, from the Trondhjem Fjord, which has been referred to the Maglemosian phase, preserves the simple profile rendering—two legs only being visible—of early Aurignacian tradition.

[1] "Les subdivisions du paléolithique supérieur et leur signification." Congrès intern. d'Anthrop. et d'Archéol. préhist., XIV^me Sess., Genève, 1912, pp. 165, 238.

It is worth noting that an art affiliated to that of the petroglyphs of the old Altaic region long survived in the figures of the Lapp troll-drums and still occasionally lingers, as I have myself had occasion to observe, on the reindeer-horn spoons of the Finnish and Russian Lapps, whose ethnic relationship, moreover, points east of the Urals. The existence of a late Paleolithic province on the Russian side is in any case now well recognized and itself supports the idea of a later shifting north and northeast, just as at a former period it had oscillated in a southwestern direction. All this must be regarded as corroborating the view long ago expressed by Boyd Dawkins[1] that some part of the old cave race may still be represented by the modern Eskimos. Testut's comparison of the short-statured Magdalenian skeleton from the rock shelter of Chancelade in the Dordogne with that of an Eskimo certainly confirms this conclusion.

On the other hand, the evidence, already referred to, of an extension of the late Paleolithic culture to a North African zone, including rock sculptures depicting a series of animals extinct there in the later age, may be taken to favor the idea of a partial continuation on that side. Some of the early rock sculptures in the south of the continent, such as the figure of a walking elephant reproduced by Dr. Peringuey, afford the clearest existing parallels to the best Magdalenian examples. There is much, indeed, to be said for the view of which Sollas is an exponent that the bushmen, who at a more recent date entered that region from the north, and whose rock painting attained such a high level of naturalistic art, may themselves be taken as later representatives of the same tradition. In their human figures the resemblances descend even to conventional details, such as we meet with at Cogul and Alpera.

Once more, we must never lose sight of the fact that from the early Aurignacian period onward a negroid element in the broadest sense of the word shared in this artistic culture as seen on both sides of the Pyrenees.

At least we now know that cave man did not suffer any sudden extinction, though on the European side, partly, perhaps, owing to the new climatic conditions, this culture underwent a marked degeneration. It may well be that, as the osteological evidence seems to imply, some outgrowth of the old Cro-Magnon type actually perpetuated itself in the Dordogne. We have certainly lengthened our knowledge of the Paleolithic. But in the present state of the evidence it seems better to subscribe to Cartailhac's view that its junction with the Neolithic has not yet been reached. There does not seem to be any real continuity between the culture revealed at Maglemose and that

[1] "Early Man in Britain," 1880, p. 233 et seq.

of the immediately superposed early Neolithic stratum of the shell mounds, which, moreover, as has been already said, evidence a change both in climatic and geological conditions, implying a considerable interval of time.

It is a commonplace of archeology that the culture of the Neolithic peoples throughout a large part of central, northern, and western Europe—like the newly domesticated species possessed by them—is Eurasiatic in type. So, too, in southern Greece and the Ægean world we meet with a form of Neolithic culture which must be essentially regarded as a prolongation of that of Asia Minor.

It is clear that it is on this Neolithic foundation that our later civilization immediately stands. But in the constant chain of actions and reactions by which the history of mankind is bound together—short of the extinction of all concerned, an hypothesis in this case excluded—it is equally certain that no great human achievement is without its continuous effect. The more we realize the substantial amount of progress of the men of the late Quaternary age in arts and crafts and ideas, the more difficult it is to avoid the conclusion that somewhere "at the back of behind"—it may be by more than one route and on more than one continent, in Asia as well as Africa—actual links of connection may eventually come to light.

Of the origins of our complex European culture this much at least can be confidently stated: The earliest extraneous sources on which it drew lay respectively in two directions—in the Valley of the Nile, on one side, and in that of the Euphrates, on the other.

Of the high early culture in the lower Euphrates Valley our first real knowledge has been due to the excavations of De Sarzec in the mounds of Tello, the ancient Lagash. It is now seen that the civilization that we call Babylonian, and which was hitherto known under its Semitic guise, was really in its main features an inheritance from the earlier Sumerian race—culture in this case once more dominating nationality. Even the laws which Hammurabi traditionally received from the Babylonian sun god were largely modeled on the reforms enacted a thousand years earlier by his predecessor, Urukagina, and ascribed by him to the inspiration of the city god of Lagash.[1] It is hardly necessary to insist on the later indebtedness of our civilization to this culture in its Semitized shape, as passed on, together with other more purely Semitic elements, to the Mediterranean world through Syria, Canaan, and Phœnicia, or by way of Assyria, and by means of the increasing hold gained on the old Hittite region of Anatolia.

Even beyond the ancient Mesopotamian region which was the focus of these influences, the researches of De Morgan, Gautier, and Lampre, of the French "Délégation en Perse," have opened up

[1] See L. W. King, "History of Sumner and Akkad," p. 184.

another independent field, revealing a nascent civilization equally ancient, of which Elam—the later Susiana—was the center. Still further afield, moreover—some 300 miles east of the Caspian the interesting investigations of the Pumpelly expedition in the mounds of Anau, near Ashkabad in southern Turkestan, have brought to light a parallel and related culture. The painted Neolithic sherds of Anau, with their geometrical decoration, similar to contemporary ware of Elam, have suggested wide comparisons with the painted pottery of somewhat later date found in Cappadocia and other parts of Anatolia, as well as in the north Syrian regions. It has, moreover, been reasonably asked whether another class of painted Neolithic fabrics, the traces of which extend across the steppes of southern Russia, and, by way of that ancient zone of migration, to the lower Danube and northern Greece, may not stand in some original relation to the same ancient province. The new discoveries, however, in the mounds of Elam and Anau have at most a bearing on the primitive phase of culture in parts of southeastern Europe that preceded the age when metal was generally in use.

Turning to the Nile Valley, we are again confronted with an extraordinary revolution in the whole point of view effected during recent years. Thanks mainly to the methodical researches initiated by Flinders Petrie, we are able to look back beyond the dynasties to the very beginnings of Egyptian civilization. Already by the closing phase of the Neolithic and by the days of the first incipient use of metals the indigenous population had attained an extraordinarily high level. If, on the one hand, it displays Libyan connections, on the other we already note the evidences of commercial intercourse with the Red Sea; and the constant appearance of large rowing vessels in the figured designs shows that the Nile itself was extensively used for navigation. Flint working was carried to unrivaled perfection, and special artistic refinement was displayed in the manufacture of vessels of variegated breccia and other stones. The antecedent stages of many Egyptian hieroglyphs are already traceable, and the cult of Egyptian divinities, like Min, was already practiced. Whatever ethnic change may have marked the establishment of Pharaonic rule, here, too, the salient features of the old indigenous culture were taken over by the new régime. This early dynastic period itself has also received entirely new illustration from the same researches, and the freshness and force of its artistic works in many respects outshine anything produced in the later course of Egyptian history.

The continuity of human tradition, as a whole, in areas geographically connected, like Eurafrica on the one side and Eurasia on the other, has been here postulated. Since, as we have seen, the Late Paleolithic culture was not violently extinguished but shows signs of survival, both north and south, we are entitled to trace elements of direct

derivation from this source among the inherited acquirements that finally led up to the higher forms of ancient civilization that arose on the Nile and the Euphrates. In many directions, we may believe, the flaming torch had been carried on by the relay runners.

But what, it may be asked, of Greece itself, where human culture reached its highest pinnacle in the ancient world and to which we look as the principal source of our own civilization?

Till within recent years it seemed almost a point of honor for classical scholars to regard Hellenic civilization as a wonder child, sprung, like Athena herself, fully panoplied from the head of Zeus. The indebtedness to oriental sources was either regarded as comparatively late or confined to such definite borrowings as the alphabet or certain weights and measures. Egypt, on the other hand, at least till Alexandrine times, was looked on as something apart, and it must be said that Egyptologists, on their side, were only too anxious to preserve their sanctum from profane contact.

A truer perspective has now been opened out. It has been made abundantly clear that the rise of Hellenic civilization was itself part of a wider economy and can be no longer regarded as an isolated phenomenon. Indirectly, its relation to the greater world and to the ancient centers to the south and east has been now established by its affiliation to the civilization of prehistoric Crete and by the revelation of the extraordinarily high degree of proficiency that was there attained in almost all departments of human art and industry. That Crete itself—the "Mid-Sea Land," a kind of halfway house between three continents—should have been the cradle of our European civilization was, in fact, a logical consequence of its geographical position. An outlier of mainland Greece, almost opposite the mouths of the Nile, primitive intercourse between Crete and the farther shores of the Libyan Sea was still further facilitated by favorable winds and currents. In the eastern direction, on the other hand, island steppingstones brought it into easy communication with the coast of Asia Minor, with which it was actually connected in late geological times.

But the extraneous influences that were here operative from a remote period encountered on the island itself a primitive indigenous culture that had grown up there from immemorial time. In view of some recent geological calculations, such as those of Baron de Geer, who by counting the numbers of layers of mud in Lake Ragunda has reduced the ice-free period in Sweden to 7,000 years, it will not be superfluous to emphasize the extreme antiquity that seems to be indicated for even the later Neolithic in Crete. The Hill of Knossos, upon which the remains of the brilliant Minoan civilization have found their most striking revelation, itself resembles in a large part of its composition a great mound or tell—like those of Mesopotamia or Egypt—formed of layer after layer

of human deposits. But the remains of the whole of the later ages represented down to the earliest Minoan period (which itself goes back to a time contemporary with the early dynasties of Egypt—at a moderate estimate to B. C. 3400) occupy considerably less than a half—19 feet, that is, out of a total of over 45. Such calculations can have only a relative value, but, even if we assume a more rapid accumulation of débris for the Neolithic strata and deduct a third from our calculation, they would still occupy a space of over 3,400 years, giving a total antiquity of some 9,000 years from the present time.[1] No Neolithic section in Europe can compare in extent with that of Knossos, which itself can be divided by the character of its contents into an early, middle, and late phase. But its earliest stratum already shows the culture in an advanced stage, with carefully ground and polished axes and finely burnished pottery. The beginnings of Cretan Neolithic must go back to a still more remote antiquity.

The continuous history of the Neolithic age is carried back at Knossos to an earlier epoch than is represented in the deposits of its geographically related areas on the Greek and Anatolian side. But sufficient materials for comparison exist to show that the Cretan branch belongs to a vast province of primitive culture that extended from southern Greece and the Ægean Islands throughout a wide region of Asia Minor and probably still further afield.

An interesting characteristic is the appearance in the Knossian deposits of clay images of squatting female figures of a pronouncedly steatopygous conformation and with hands on the breasts. These in turn fit on to a large family of similar images which recur throughout the above era, though elsewhere they are generally known in their somewhat developed stage, showing a tendency to be translated into stone, and, finally—perhaps under extraneous influences both from the north and east—taking a more extended attitude. These clearly stand in a parallel relationship to a whole family of figures with the organs of maternity strongly developed that characterize the Semitic lands and which seem to have spread from there to Sumeria and to the seats of the Anau culture.

At the same time this steatopygous family, which in other parts of the Mediterranean Basin ranges from prehistoric Egypt and Malta to the north of mainland Greece, calls up suggestive reminiscences of the similar images of Aurignacian man. It is especially interesting to note that in Crete, as in the Anatolian region where these primitive images occur, the worship of a mother goddess predominated in later times, generally associated with a divine child—a worship which

[1] For a fuller statement I must refer to my forthcoming work, "The Nine Minoan Periods" (Macmillans), Vol. 1: Neolithic section.

later survived in a classical guise and influenced all later religion. Another interesting evidence of the underlying religious community between Crete and Asia Minor is the diffusion in both areas of the cult of the Double Axe. This divine symbol, indeed, or "Labrys," became the special emblem of the palace sanctuary of Knossos itself, which owes to it its traditional name of Labyrinth. I have already called attention to the fact that the absorptive and disseminating power of the Roman Empire brought the cult of a male form of the divinity of the Double Axe to the Roman wall and to the actual site on which Newcastle stands.

The fact should never be left out of sight that the gifted indigenous stock which in Crete eventually took to itself, on one hand and the other, so many elements of exotic culture, was still deep-rooted in its own. It had, moreover, the advantages of an insular people in taking what it wanted and no more. Thus, it was stimulated by foreign influences but never dominated by them, and there is nothing here of the servility of Phœnician art. Much as it assimilated, it never lost its independent tradition.

It is interesting to note that the first quickening impulse came to Crete from the Egyptian and not from the oriental side—the eastern factor, indeed, is of comparatively late appearance. My own researches have led me to the definite conclusion that cultural influences were already reaching Crete from beyond the Libyan Sea before the beginning of the Egyptian dynasties. These primitive influences are attested, amongst other evidences, by the forms of stone vessels, by the same esthetic tradition in the selection of materials distinguished by their polychromy, by the appearance of certain symbolic signs, and the subjects and shapes of seals which go back to prototypes in use among the "old race" of the Nile Valley. The impression of a very active agency, indeed, is so strong that the possibility of some actual immigration into the island of the older Egyptian element, due to the conquests of the first Pharaohs, can not be excluded.

The continuous influence of dynastic Egypt from its earliest period onward is attested both by objects of import and their indigenous imitations, and an actual monument of a middle empire Egyptian was found in the Palace Court of Knossos. More surprising still are the cumulative proofs of the reaction of this early Cretan civilization on Egypt itself, as seen not only in the introduction there of such beautiful Minoan fabrics as the elegant polychrome bases but in the actual impress observable on Egyptian art even on its religious side. The Egyptian griffin is fitted with Minoan wings. So, too, on the other side we see the symbols of Egyptian religion impressed into the service of the Cretan nature goddess, who in certain respects

was partly assimilated with Hathor, the Egyptian cow goddess of the underworld.

My own most recent investigations have more and more brought home to me the all-pervading community between Minoan Crete and the land of the Pharoahs. When we realize the great indebtedness of the succeeding classical culture of Greece to its Minoan predecessor the full significance of this conclusion will be understood. Ancient Egypt itself can no longer be regarded as something apart from general human history. Its influences are seen to lie about the very cradle of our own civilization.

The high early culture, the equal rival of that of Egypt and Babylonia, which thus began to take its rise in Crete in the fourth millennium before our era, flourished for some two thousand years, eventually dominating the Ægean and a large part of the Mediterranean Basin. To the civilization, as a whole, I ventured, from the name of the legendary king and lawgiver of Crete, to apply the name of "Minoan," which has received general acceptance; and it has been possible now to divide its course into three ages—early, middle, and late, answering roughly to the successive Egyptian kingdoms, and each in turn with a triple subdivision.

It is difficult, indeed, in a few words to do adequate justice to this earliest of European civilizations. Its achievements are too manifold. The many-storied palaces of the Minoan priest kings in their great days, by their ingenious planning, their successful combination of the useful with the beautiful and stately, and last but not least, by their scientific sanitary arrangements far outdid the similar works, on however vast a scale, of Egyptian or Babylonian builders. What is more, the same skillful and commodious construction recurs in a whole series of private mansions and smaller dwellings throughout the island. Outside "broad Knossos" itself flourishing towns spring up far and wide on the country sides. New and refined crafts were developed, some of them like that of the inlaid metal work, unsurpassed in any age or country. Artistic skill, of course, reached its acme in the great palaces themselves, the corridors, landings, and porticoes of which were decked with wall paintings and high reliefs, showing in the treatment of animal life not only an extraordinary grasp of nature but a grandiose power of composition such as the world had never seen before. Such were the great bull-grappling reliefs of the sea gate at Knossos and the agonistic scenes of the great palace hall.

The modernness of much of the life here revealed to us is astonishing. The elaboration of the domestic arrangements, the staircases story above story, the front places given to the ladies at shows, their fashionable flounced robes and jackets, the gloves sometimes seen on their hands or hanging from their folding chairs, their

very mannerisms as seen on the frescoes, pointing their conversation with animated jestures—how strangely out of place would it all appear in a classical design. Nowhere, not even at Pompeii, have more living pictures of ancient life been called up for us than in the Minoan Palace of Knossos. The touches supplied by its closing scene are singularly dramatic—the little bathroom opening out of the Queen's parlor, with its painted clay bath, the royal draught-board flung down in the court, the vessels for anointing and the oil jar for their filling ready to hand by the throne of the priest-king, with the benches of his consistory round and the sacred griffins on either side. Religion, indeed, entered in at every turn. The palaces were also temples, the tomb a shrine of the great mother. It was perhaps owing to the religious control of art that among all the Minoan representations—now to be numbered by thousands—no single example of indecency has come to light.

A remarkable feature of this Minoan civilization can not be passed over. I remember that at the Liverpool meeting of this association in 1896—just before the first results of the new discoveries in Crete were known—a distinguished archeologist took as the subject of an evening lecture "Man before writing," and, as a striking example of a high culture attained by "Analfabeti," singled out that of Mycenæ—a late offshoot, as we know now, from Minoan Crete. To such a conclusion, based on negative evidence, I confess I could never subscribe—for had not even the people of the Reindeer Age attained to a considerable proficiency in expression by means of symbolic signs? To-day we are able to trace the gradual evolution on Cretan soil of a complete system of writing from its earliest pictographic shape, through a conventionalized hieroglyphic to a linear stage of great perfection. In addition to inscribed sealings and other records some 2,000 clay tablets have now come to light, mostly inventories or contracts; for though the script itself is still undeciphered the pictorial figures that often appear on these documents supply a valuable clue to their contents. The numeration also is clear, with figures representing sums up to 10,000. The inscribed sealings, signed, countermarked, and countersigned by controlling officials, give a high idea of the elaborate machinery of government and administration under the Minoan rulers.

The minutely organized legal conditions to which this points confirm the later traditions of Minos, the great lawgiver of prehistoric Crete, who, like Hammurabi and Moses, was said to have received the law from the God of the Sacred Mountain. The clay tablets themselves were certainly due to oriental influences, which make themselves perceptible in Crete at the beginning of the late Minoan Age, and may have been partly resultant from the reflex action of

Minoan colonization in Cyprus. From this time onward eastern elements are more and more traceable in Cretan culture and are evidenced by such phenomena as the introduction of chariots—themselves perhaps more remotely of Aryan-Iranian derivation—and by the occasional use of cylinder seals.

Simultaneously with its eastern expansion, which affected the coast of Phœnicia and Palestine as well as Cyprus, Minoan civilization now took firm hold of mainland Greece, while traces of its direct influence are found in the west Mediterranean basin—in Sicily, the Balearic Islands, and Spain. At the time of the actual conquest and during the immediately succeeding period the civilization that appears at Mycenæ and Tiryns, at Thebes and Orchomenos, and at other centers of mainland Greece, though it seems to have brought with it some already assimilated Anatolian elements, is still in the broadest sense Minoan. It is only at a later stage that a more provincial offshoot came into being to which the name Mycenæan can be properly applied. But it is clear that some vanguard at least of the Aryan Greek immigrants came into contact with this high Minoan culture at a time when it was still in its most flourishing condition. The evidence of Homer itself is conclusive. Arms and armor described in the poems are those of the Minoan prime, the fabled shield of Achilles, like that of Herakles described by Hesiod, with its elaborate scenes and variegated metal work, reflects the masterpieces of Minoan craftsmen in the full vigor of their art; the very episodes of epic combat receive their best illustration on the signets of the great days of Mycenæ. Even the lyre to which the minstrel sang was a Minoan invention. Or, if we turn to the side of religion, the Greek temple seems to have sprung from a Minoan hall, its earliest pediment schemes are adaptations from the Minoan tympanum—such as we see in the Lion's Gate—the most archaic figures of the Hellenic goddesses, like the Spartan Orthia, have the attributes and attendant animals of the great Minoan mother.

Some elements of the old culture were taken over on the soil of Hellas. Others which had been crushed out in their old centers survived in the more eastern shores and islands formerly dominated by Minoan civilization, and were carried back by Phœnician or Ionian intermediaries to their old homes. In spite of the overthrow which about the twelfth century before our era fell on the old Minoan dominion and the onrush of the new conquerors from the north, much of the old tradition still survived to form the base for the fabric of the later civilization of Greece. Once more, through the darkness, the lighted torch was carried on, the first glimmering flame of which had been painfully kindled by the old cave dwellers in that earlier Paleolithic world.

The Roman Empire, which in turn appropriated the heritage that Greece had received from Minoan Crete, placed civilization on a broader basis by welding together heterogeneous ingredients and promoting a cosmopolitan ideal. If even the primeval culture of the Reindeer Age embraced more than one race and absorbed extraneous elements from many sides, how much more is that the case with our own which grew out of the Greco-Roman! Civilization in its higher form to-day, though highly complex, forms essentially a unitary mass. It has no longer to be sought out in separate luminous centers, shining like planets through the surrounding night. Still less is it the property of one privileged country or people. Many as are the tongues of mortal men, its votaries, like the immortals, speak a single language. Throughout the whole vast area illumined by its quickening rays, its workers are interdependent and pledged to a common cause. * * *

THE GREAT DRAGON OF QUIRIGUA, GUATEMALA.[1]

By W. H. Holmes,

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[With 10 plates.]

In February, 1916, the writer had the good fortune to become a member of the Carnegie Institution's archeological expedition to Central America. Under the able directorship of Sylvanus G. Morley, the fascinating work of exploring and studying in detail the remarkable remains of ancient Maya culture was vigorously carried forward. The especial object of this year's expedition was the discovery of additional sculptured inscriptions embodying glyphic dates—for it is the dates, now read with facility, that furnish the skeleton of Mayan history.

Among the ancient ruined cities visited while the writer was associated with the expedition was Quirigua in eastern Guatemala, the subject of much scientific attention during recent years. On arriving at the site our party emerged from the tropical forest that surrounds the few acres of cleared ground, called a park, in which the ruins are inclosed, and came suddenly upon a group of the great sculptured monoliths. For a moment we were puzzled by a curious scaffolding and platform some 20 feet in height erected against the face of an elaborately sculptured stela. Mounted on this platform without apparent protection from the sun was descried the figure of a man posing before a large canvas. It proved to be Mr. Joseph Lindon Smith, the master portrayer of ancient monuments engaged in painting the portrait of the mysterious personage whose heroic form is carved in high relief in the face of the monument. The several paintings completed by Mr. Smith are preserved in the Peabody Museum of Ethnology and Archaeology, Cambridge.

PROBLEMS OF MAYAN HISTORY.

The reading of the dates, inscribed in glyphic characters on the sculptured monuments, and in ancient manuscripts, is a most im-

[1] Reprinted with author's revision from Art and Archaeology, Washington, D. C., December, 1916.

portant first step in the attempt to solve the problems of Mayan history, but unfortunately this achievement is not an open sesame to the full story of the monuments of the ancient civilization. Each of the great carved monoliths is a greater riddle than the Egyptian Sphinx. There is no short cut to the unfolding of their story, and archeology must take up the tedious but fascinating task.

With the monuments before us and a limited number of dates to begin with, we seek to fill out the outline thus meagerly sketched. We are doubtless safe in assuming that early in the Christian era certain groups of the American race, rising distinctly above the general level of barbarism, began the construction of stone buildings and the carving of monuments devoted to the service of their gods. They flourished for a few centuries only, and had passed the zenith of their cultural development long before the Spanish conquerors in the sixteenth century penetrated the tropical forests of Central America. Numerous important cities that had arisen were abandoned and in ruins and their story wholly forgotten by the decadent generations of the Columbian period.

THE RUINS OF QUIRIGUA.

The ancient Maya city, now known as Quirigua, is represented to-day by a group of enigmatical stone monuments only recently retrieved from the dense tropical forest which has buried them for unnumbered centuries. These monuments comprise a large number of buildings and monolithic sculptures. Such buildings as remain are in an advanced state of ruin, while others are represented by mere mounds and platforms of stone and earth. The sculptures are scattered over the various courts and plazas, and bear mute testimony to the high state of culture achieved by the people during the period of their ascendancy—a period assigned by Morley to the early centuries of the Christian era. The monolithic sculptures are of two classes—tall, slender shafts known as stelæ, thought to have special chronological significance, and low, massive forms sometimes referred to as altars.

The stelæ are 13 in number and range from 11 to 26 feet in height. They are elaborately carved with representations of richly appareled personages, both male and female, with associated symbolic devices and glyphic inscriptions. The massive monuments are 20 in number and are extremely diversified in sculptural treatment and in the subject matter embodied. It is assumed, with a high degree of probability, that the entire group of monuments was the seat of the religious establishment or establishments of the city. All monuments of perishable material and all nonmonumental portions of the city have long since disappeared.

VIEW OF THE GREAT DRAGON, THE HUMAN FIGURE SERVING TO INDICATE ITS REMARKABLE SIZE.

THE WEST FACE OF THE GREAT DRAGON.

The task of describing these monuments has been undertaken by Maudslay, Hewett, and others, and to the publications of these explorers those who would go deeply into the subject are referred. A single example of the sculptures—a work that takes high rank in the world of art—is selected for detailed presentation in this place.

THE GREAT DRAGON.

The stone.—The massive sculpture sometimes called the Great Turtle may well be regarded as the sculptural masterpiece par excellence of the American race. It is a somewhat ovoid mass of coarse-grained sandstone of warmish gray color weighing about 20 tons. It is upward of 7 feet in height and is 11 feet 6 inches in greater diameter. When the School of American Archaeology began its work here the surface was deeply coated with moss and other tropical growths, which were carefully cleaned off by Dr. Hewett in 1910, repeating the task of Maudslay some 20 years earlier. The surface is now much weather stained, displaying streaks and blotches of dark color, probably due to the weathering out of ferruginous matter contained in the stone. The master sculptor appears to have utilized in a measure the original irregularities of the great block, the flattish base of which rests at the ground level on a floor composed of three hewn stone slabs.

The origin of the block can not be determined with certainty, although it must have been brought from quarries in the bluffs 2 or more miles to the west. That it should have been carried by any means at the command of the aborigines over the soft alluvial flood plain of the Motagua is, however, almost beyond belief; but there seems no alternative to this conclusion, unless we should venture to assume decided changes of climate or altitude since that titanic task was accomplished. It now lies within the ceremonial plaza near the southern margin, the two principal sculptured fronts facing north and south.

East and west faces.—Approaching the stone from the east it is observed that the entire surface is elaborately sculptured, now in high, now in low relief, and in graceful arrangements of strange forms so diversified and intricate that analysis of the mazelike complex seems at first quite impossible (pl. 1). There is a compounding and confusion of natural elements—human, reptilian, avian, and grotesque—in all degrees of convention intermingled with formal patterns, scrolls, cartouches, and glyphic inscriptions, altogether amazing, yet distinctly attractive and highly decorative. Notwithstanding our failure at first to comprehend a single feature of the work, the touch of the master was recognized in every form and line. The west side (pl. 2) is nearly identical in treatment and proved to be

equally incomprehensible; and the reason for this, as was afterwards learned, is the fact that the figures on these faces are incomplete in themselves, being continuations and appendages from the sculptured figures of the upper surface, which, to be traced and understood, must be approached by the student from that surface.

The north face.—Proceeding to examine the work in detail, we pass to the north face (pl. 3), and attention is at once directed to an elaborately and elegantly costumed human figure, strongly yet delicately carved, which occupies a central position in the broad face of the block. The figure is seated, Buddha fashion, and presents a placid and dignified mien. Including the headdress, it is about 7 feet in height. Although the features are somewhat mutilated, they distinctly suggest a young and comely person, possibly a female, although there appears to be some difference of opinion among students on this point.

Maudslay's drawing of this figure, reproduced in large part in plate 4, gives to the face a delicacy and refinement somewhat at variance with typical Mayan representations, and as a matter of course also fails to convey an adequate impression of the boldness of the relief. The right hand grasps a ceremonial device known as the manikin scepter, doubtless significant of the office and dignity of the personage represented, while the left supports a small, highly embellished, shieldlike device or symbol. Joyce may be right in his suggestion that the scepter is possibly a highly elaborated form of the hatchet, the almost universal weapon of the Indian warrior and a common symbol of authority.

The costume is of superb design, testifying to the advanced state of culture and refinement attained by the people of Quirigua. The details are so elaborate as to defy adequate description, hence the drawings and photographs must be relied upon mainly to tell the story. The headdress embodies a crownlike band over the forehead, surmounted by a complex of grotesque masks with deep-set eyes and vicious fangs and a maze of scrolls, plumes, and symbols, all sculptured with a vigor and delicacy worthy of the masters of the Orient. Connecting with the top of the headdress are two pairs of strange appendages which extend to the right and left over the upper margin of the stone; they are ornamented with incised checkerwork and various devices in relief. A graceful necklace spreads over the shoulders of the figure and expands across the chest into a broad gorget, in the center of which is set a grotesque mask. The mask is repeated at the waist, and from this the garb extends down over the crossed legs in an apronlike arrangement embodying various serpentine elements and symbols, and terminating in radiating plumes. The wristlets and ear ornaments are of usual Mayan types, the latter extending out over the shoulders.

THE GREAT DRAGON OF QUIRIGUA, NORTH FRONT, SHOWING SCULPTURED HUMAN FIGURE, SEVEN FEET IN HEIGHT, SEATED IN ITS MOUTH.

SCULPTURED HUMAN FIGURE SEATED IN THE DRAGON'S MOUTH. SEVEN FEET IN HEIGHT.
(MAUDSLAY.)

Seeking to determine the exact relation of the sculptured figure to the strange forms which surround it, we discover that it sits in the mouth of a great reptilian monster, whose upper jaw is arched above, passing behind the headdress, while closing in on the figure at the sides the tusklike fangs of the reptile are to be seen. The outer surfaces of the jaws are embellished with scalelike groups of glyphs and cartouches, and to the right and left in the curves of the upturned jaw are the deep-set eyes of the monster, the pupils of which are embellished with glyphlike figures in relief. Beneath the figure the lower jaw of the reptile appears with great rounded fangs at the sides. At the right and left near the base and connecting back over the sides are sculptured panels in which grotesque and distorted demons appear, each holding tightly against his form a device having the appearance of a glyph. The possible significance of the human figure and its relation to the reptilian monster will be referred to later.

The south face.—Passing to the south face of the stone, we discover, occupying a central place in the surface, a great masklike visage of forbidding aspect, of the type characteristic of the "Long-nosed God" (pl. 5). Although this deity is given varying attributes in the different Mayan centers of culture, it is thought probable that in the present connection it may represent the god of the underworld and possibly also of death. The great staring eyes are set in features of strange conformation, and the wide mouth displays fangs with molars at the right and left and the usual tusk coils springing from the outer corners. At the sides are the ears, embellished with squarish loops and pendants, while above rises the headdress of unique and striking design. Inclosing the face and extending in terraced form across the headdress is a glyphic inscription neatly carved and tastefully arranged. Above the forehead and surrounded by the inscription is a beautifully designed scroll-inclosed panel from which looks out a human face, the hands also appearing at the lower margin, while above and extending to the upper surface of the stone is a superbly chiseled device set against the crown of plumes which expands widely to right and left. Medallionlike embellishments are overlaid upon the plumes, which terminate on the shoulders of the image in an ornamental beaded appendage.

To the right and left of the inscription richly embellished, rounded, columnlike forms or shoulders are encountered which connect backward at the base with flattish scaled plates suggesting the flippers of the great sea turtle, and it is doubtless these features that gave the original name—the "Great Turtle"—to the monument. Observing their termination in what appears to be a claw, it is suggested that they were not intended as representations of the flippers of any particular natural form, but rather of a mythical reptilian divinity of non-

descript characters. Their presence, recalling the open jaws at the northern end, makes it apparent that the sculpture as a whole was intended to represent the mythical bicephalous reptilian monster sometimes referred to as the Earth Monster or God, a frequently recurring conception in the native pantheon. We may well assume that the sculpture embodies the Quiriguan conception of this deity, the forms of which are elaborated in various ways and in endless combinations according to the attributes assigned to it in the mythology of the different peoples. A variant of this conception, found in Copan, Honduras, is shown in an accompanying illustration (pl. 6).

The shoulders of the southern end of the idol are embellished with vertical lines of glyphs and cartouches, one group of which, illustrated herewith, is the glyphic date, while beneath, on each side, are panels inclosing glyph-bearing demons. Encircling the arms above the elbow are bracelets of elegant design. The shoulders are partially covered by the flaring featherwork of the headdress and by scrollwork which probably represents the outer elaboration of the jaws of the reptile, the main portions of which appear to be hidden by the inscription.

The upper surface.—Climbing to the back of the strange monster the imagination of the observer is profoundly stirred. Although representing no known form in any kingdom of nature—a pure work of the imagination—a strange compounding and overlapping of human, reptilian, and avian elements, it conveys vividly the impression of a living thing—a dragon outdragoning all the composite monsters of the Orient. So virile are the forms, so tense the coiling, so strong the impression of life, that a thrill almost of apprehension steals over one, for there is a distinct suggestion that the bulging imprisoned inner monster might break its bonds, uncoil its length, and slide away into the deep shadows of the forest immediately at hand. This extraordinary face of the sculpture is shown in an accompanying illustration taken from a model prepared by the American Museum of Natural History, in which institution Maudslay's full-size cast of the original is installed (pl. 7).

The symbolism.—It is not questioned that the great groups of monumental remains that mark the sites of the ancient Maya cities owe their existence to religion and that they were devoted to the service of the gods. The temples were the sanctuaries of the divinities, the resorts of their mortal servitors, and storage places for paraphernalia and the offerings of the faithful. The sacred inclosures, the courts and plazas in which the great stone monoliths were set up, were the conjuring places of the priesthood where the gods were consulted and invoked—the sacred precincts where on festive occasions the people were permitted to enter and to take part in elaborate ceremonies and where they were made to realize the power

THE GREAT DRAGON, SOUTH FRONT, SHOWING MASK OF THE LONG-NOSED GOD, SURROUNDED BY GLYPHIC INSCRIPTIONS. THE DATE OCCURS AT THE TOP OF THE COLUMN ON THE RIGHT SHOULDER.

AN EXAMPLE OF THE TWO-HEADED DRAGON FOUND AT COPAN, HONDURAS.

and glory of the gods, thus insuring their willing subservience to the temporal powers. To the people the stelæ, probably originally the images of rulers set up at stated intervals, as the dates indicate, were divinities to be revered and served. The zoomorphic divinities represented by the massive altarlike monuments were doubtless in the native mind definitely individualized, vitalized beings, eternal and endowed with varied powers of extraordinary potency. When, under the inspired direction of the shamanistic master, the sculptor carved a wing, it was not of a bird he thought; when he carved the reptilian fangs, it was not of a serpent he thought; when he carved the turtlelike flippers, he thought not of a turtle. In all cases he had in mind a being or divinity, which, though a work of the imagination, pure and simple, was to him as real as the living forms with which nature surrounded him.

The assemblage of attributes represented in the sculptured dragon were not necessarily the invention of the people or the priesthood of Quirigua, for they must have grown up with the growth of myth through unnumbered generations. It is probable that they were but dimly understood even by the officials who directed the sculpture of their images and who assumed to be the familiars of the gods. We may be quite sure that every one of the multitude of features carved with so much labor and artistic care had associated with it some element of myth. The dragon was doubtless regarded as the material embodiment of a divine being perhaps of the highest order in the native pantheon. May it then not be, as some have surmised, that this image impersonates the Earth Monster, the World God, and that from the wide-open jaws, facing the ceremonial plaza, issued the divinity of the world of man, that through the glyph-hidden jaws of the southern end peered the grotesque demon of the underworld, and that the strangely compounded visage of the upper surface was the guardian of the sky? We must remain content, however, with mere surmises, until research penetrates more deeply into the mysteries of Maya mythology. Of one thing we may be assured—our imaginings, howsoever elaborated and fanciful, can be but as shadows compared with the complex imagery with which the 2-headed 12-eyed dragon was invested by the ancient worshipers of Quirigua.

The functions.—The sculptured monoliths of Quirigua were carved with a definite purpose in view and had a particular and very important function to perform. Although the highest technical skill of the people was lavished upon them, and the esthetic perfection of the result was kept constantly in view, the primary purpose was not the gratification of the craving for beauty. They had a vital bearing on the welfare of the people—a practical function of the greatest moment. Through the idols the mysterious powers of nature, which they were believed to represent, were reached, and

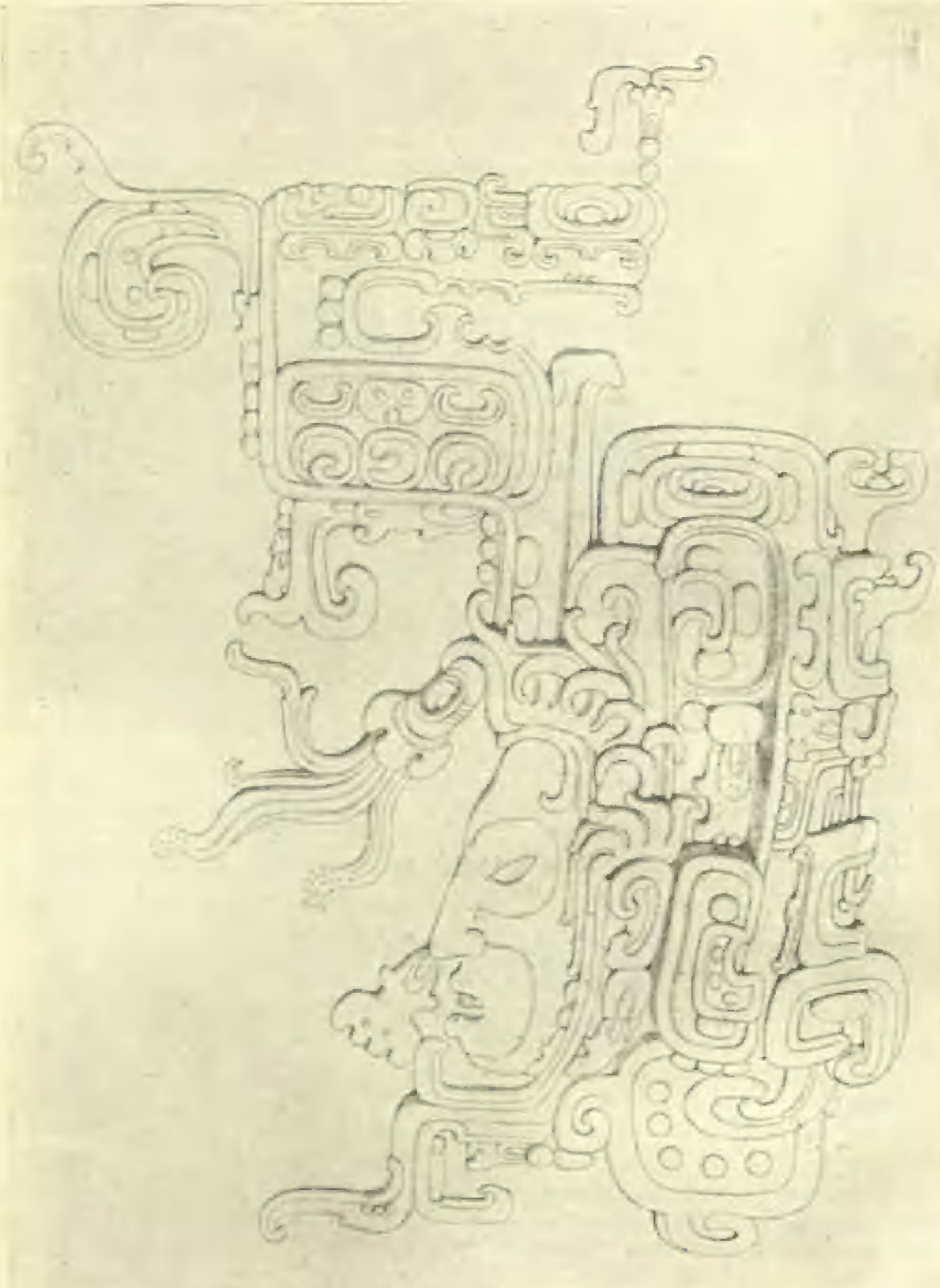
by means of an elaborate system of shamanistic conjurings and appeals, were placated, controlled, and utilized in the interests nominally of the people, actually of the shamanistic establishment.

The story of the development of this strange system of invocation of the gods through zoomorphic forms furnishes one of the most interesting and important chapters in the culture history of the American race, operating at all times as a strong force in the direction of material, intellectual, and artistic advancement, and this notwithstanding the fact that the whole divine structure was a work of the imagination pure and simple. The beginnings of the function of the works which we call idols is to be sought in the vague imaginings of primitive man when he first essayed to localize and interpret the mysterious powers of nature to which he found himself subject.

As the result of his speculations he reached the generalization that all things in nature were imbued with life and power in some degree like his own; and special things, as stones, trees, animals, the heavenly bodies, were regarded as having exceptional potency for good or evil; some were adopted by him as protective agencies, as charms and talismans—incipient divinities—while others were feared and avoided as agencies of evil.

In time, with the growth of myth, the imagination reached beyond mere natural forms, conjuring up new beings, largely zoomorphic in type, having special supernatural attributes and powers. Certain reptilian forms, on account of their death-dealing powers and mysterious ways were prime favorites, and in time images of these, with strange variations, took the place of the real creatures and were invested with attributes and powers in a superior degree. With the further growth of myth the conceptions became composites of unrelated originals, and the images were elaborated to the extent of the mechanical and artistic capabilities of the people. Carved in wood or stone and modeled in stucco or in clay, these became the centers about which sanctuaries were built and ceremonies were conducted—all designed to cultivate the favor of the divinities whose forms they represented for good to themselves and evil to their enemies. These activities, growing in importance, led to the organization of bodies of religious servitors, of a shamanistic priesthood whose function it was to care for the sanctuaries, conserve the sacredness of the idols, and formulate and conduct the elaborate rituals. But the activities of the priestly establishments thus developed, based primarily on the idea of appeal to the gods in the interests of the community for the commonweal, came, by a natural and inevitable extension of unquestioned power, to have other and ulterior purposes in view.

TOP VIEW OF THE GREAT DRAGON FROM A MODEL OF THE SPECIMEN PREPARED BY THE AMERICAN MUSEUM OF NATURAL HISTORY.



DRAWING OF A PORTION OF THE WESTERN FACE OF THE DRAGON, SHOWING THE GRACEFUL DECORATIVE ELABORATION OF THE REPTILIAN UPPER JAW AND THE HUMAN VISAGE ISSUING FROM THE MOUTH. (AFTER MAUDSLAY.)

The fateful trend.—There is thus another side to the story of the functions of the idols and of the vast religious establishments of the Maya cities. Under the undisputed control of an organized body of wide influence and a religio-political system hoary with age, the people doubtless believed themselves working for the common good and in obedience to the bidding of dieties whose reality and authority were constantly impressed upon them. They had no means of arriving at a correct knowledge of the truth that the gods of the entire pantheon were mere fictions and that the revered priesthood, although the embodiment of the highest wisdom, the promoters of learning, and perhaps also the conservators of moral standards, was at the same time a body of organized parasites, their position and authority being sustained by the cunning use of the images in stone and the complex system of festivals connected with their conjuration.

We may not be far amiss in surmising that under the evergrowing requirements of the shamanistic body in carrying forward their ambitious schemes, the energies and resources of the people were absorbed in larger and larger measure—in quarrying, hewing, transporting, building, carving, providing, and serving, and that as the natural agencies of deterioration and decay made inroads on the splendid establishments which they had builded, they were called on to quarry and carve and build again in an ever-losing struggle against the elements and against the undetected incubus of the ambitious and selfish priestcraft. We can readily conceive that these conditions prevailed until the energies and resources of the people were impaired or exhausted, and that gradually the authority of the priesthood and the demands of the gods through them elicited no response from the impoverished people, so that disintegration and decay rapidly supervened, and that the end came on apace, as it must come to all structures builded on sand, and more especially to those builded on the treacherous sands of the imagination.

It thus appears that to account for the decay of the Mayan culture and the ruin of its wonderful cities we do not have to call primarily on the more drastic agencies of destruction—war, pestilence, changes in the level of the land, floods, and earthquakes, one or all of which, however, may have aided in precipitating the disaster. The seeds of decay were inherent in the system, as they are inherent in every organization and structure of whatsoever kind that involves the long-continued, ever-growing, and unrequited waste of the energies and resources of a people.

Esthetic significance.—While the great dragon of Quirigua may be regarded as representing the culminating stage of religious art in aboriginal America, it serves also to mark the highest level reached in esthetic refinement. The religious motive was the strong dynamic force which, more than all other agencies combined, carried culture

forward through the prolonged stages of savagery and barbarism to the borderland of civilization. Due to a highly centralized religio-political form of government, the people and their resources were readily available in carrying out great undertakings, and rapid strides in the development of institutions and arts were possible. The esthetic faculty dependent largely on nonesthetic activities for its manifestations was thus afforded its greatest opportunity.

The arts of taste had their origin, as had religion, in the state of savagery; and with some very ancient peoples, as the Troglodytes of western Europe, decided advance was made in both graphic and plastic representation of life forms, and this quite independently, so far as evidence is available, of any religious association or influence. The Maya in the beginning may have passed through a corresponding stage of nonsymbolic art, but howsoever this may be, it was not until religious symbolism gave special significance to the subject matter of representative art, that particular advance was made toward the higher esthetic expression. With this great group, as with the American peoples generally, the esthetic in its higher manifestations grew as a vine upon the strong stem of religious symbolism. Religion furnished the conception and the energy and skill necessary to its realization; it prepared the design, supervised its application to the stone, and drove the chisel that carved it. It demanded results in form, finish, and embellishment of the highest order, for in the view of their devotees the gods appreciated the beautiful as well as the essential. We do not lose sight of the fact, however, that appreciation of the qualities regarded as pleasing to the gods had its origin in that which was pleasing to the man. Certain qualities of form, line, color, and arrangement gave pleasure to the eye; certain qualities of finish gave pleasure to the touch, and this appreciation of the qualities called esthetic, was a thing of slow growth in the human mind, but of great moment in the history of culture. To the pleasure afforded by perfected qualities of the works themselves were added always the incentive of religious fervor, the ambition to excel, and the fascination of creating for creation's sake.

The importance of the esthetic element in Maya art can hardly be overestimated. It is doubtful if any people at a corresponding stage of cultural evolution was more highly gifted with artistic genius and appreciation and gave more attention to its application to all forms of art than the Mayan race. Every plastic form and every line of the dragon bear testimony to this fact. It was not religion that stipulated that no straight line and no right angle should appear in the image of the dragon; it was not religious restriction that provided that no curve should be the arc of a circle, that every curve should be subtle, and that all outlines of glyphs and

DRAWING OF A PORTION OF THE RELIEF SCULPTURE OF THE EASTERN FACE OF THE DRAGON, SHOWING ONE OF THE LATERAL EYES AND THE REMARKABLE EMBELLISHMENTS SURROUNDING IT. (AFTER MAUDSLAY.)

1. A DEMON SPACE FILLER, PROBABLY A HIGHLY ELABORATED GLYPH.

2. A DEMON SPACE FILLER, PROBABLY A HIGHLY ELABORATED GLYPH.

cartouches should take the roundish, calculiform character. Every feature of design had complete esthetic supervision (pls. 8, 9). Throughout America plastic freehand methods always prevailed over the mechanical. In the creation of this monument the great motor force was religion, but the ever-watchful esthetic impulse joined hands with that force in making it a masterpiece of art.

Dependence of art on religion is amply shown in what has been said, but the fact may be further illustrated. If in the course of the progressive decadence of a primitive culture the religious impulse should lose its hold on the people, all save the most ordinary esthetic activities would cease and it is manifest that no additional block would be hewn from the quarry, no great stone would be carried to sacred precinct, no mythic conception would be applied to the stone, and no hand would be available to undertake the task of realization.

It is observed that the ancient Maya sculptor abhorred blank spaces in his designs and also that in cases there is an overcrowding of subject matter, but no people has ever filled in waste spaces more effectively than the sculptors of Quirigua. The space-filling figures are not, however, mere meaningless embellishments, but are doubtless generally significant, having reason to be in the particular places where they are introduced. In this particular masterpiece the introduced elements embody animals, human and grotesque figures with symbols and embellishments all in agreeable accord with the composition proper. A somewhat definite idea of the general character of the design and the remarkable elaboration and beauty of the work can be gained by a study of the photographs and drawings herewith presented (pl. 10).

Technic aspect.—The technic history of the great stone begins with its removal from the quarry and transportation to the present spot. How this herculean task was performed must remain a matter of speculation. With a people unacquainted with the highly developed appliances of civilization, the task would seem beyond the possibility of accomplishment. It is quite impossible to say whether the removal was by land or by water. If by land, a road had to be constructed over ground now rough, now yielding and unstable, and a great force of men with rollers and ropes would be required. If by water, a broad and deep canal had to be dug, and a raft of large proportions constructed and launched to sustain the immense weight. Unless decided evidence of the use of the latter method appears, the former must be accepted as the one probably employed.

The designing and carving of the monument, the methods and means, are matters of great scientific interest on which we have but meager light. It was not a task within the reach of an uncultured people. The complicated conception had to be clearly in mind, the

design had to be worked out in minute detail, and the application of the drawings to the irregular rounded surface of the stone was a matter of no little difficulty. As a preliminary step the shape of the stone had to be modified to suit the purpose, the surface smoothed before the outlines could be applied in pigment, and the many features adjusted to their several places preparatory to the beginning of the sculptor's work.

The execution of the work is a deep mystery and its successful completion a great marvel. A lump of coarse sandstone—according to Maudslay "a breccia composed of feldspar, mica, and quartz, very absorbent, and weighing about 130 pounds to the cubic foot"—had to be attacked with tools the nature of which remains to-day a matter of conjecture. It is generally believed that these people were without hard metal tools, and although stone tools were probably equal to the task, few traces of such tools applicable to the purpose have been found. We thus pause before a second mystery, for had stone tools been used in the arduous and prolonged task of crumbling with pick and hammer and smoothing by abraders, they would still exist and ought to be found frequently in the work of clearing and excavation, for it seems highly probable that the carving of the various monuments was carried on, not only on the spot where they now stand, but after final placement upon their foundations. If bronze were used, it may have disappeared by decay. However, there are no traces of the use of this metal in any form and no documentary testimony supporting the hypothesis of its use by the Mayan peoples.

A striking feature of the sculptural work of Quirigua, well illustrated in the example here presented, is the masterly workmanship. The design is adjusted perfectly to the shape of the stone, and there is no suggestion of incompetence on the part of the sculptor and no indication of the lack of effectiveness on the part of the implements used. The forms, shallow or deep, simple or complex, are all carved with equal directness and vigor. The chisel may not have accomplished all that the conception required, for ideals may rise entirely above the capacity of material embodiment, but there is no suggestion of hesitation or inefficiency in the completed work.

Culture status.—The date inscribed in hieroglyphic characters on this monument occurs on the left shoulder of the southern front, and, as read by Morley, corresponds with the year 525 of the Christian era. Certain groups of the Maya race, including the people of Quirigua, had made such advance in culture as to justify the claim that they had attained the state known as civilization. Glyphic writing was well advanced, and students are pretty well agreed that a phonetic method of record, the achievement of which best marks

the close of the barbarian and the beginning of the civilized state, was an accomplished fact—not the perfected representation of elementary sounds, perhaps, but rather symbols for words and syllables. In many of the arts the Maya had made remarkable progress—in architecture, sculpture, the cutting of gems, pottery, the textile art, and metallurgy, they could compare favorably with the several countries of central and western Europe at corresponding periods down to the year 525 A. D.

The future.—The great stone structures of Quirigua crumbled beneath the attacks of destructive climatic agencies, aided possibly by earthquakes and other natural forces, and were deserted by an impoverished and disheartened people; and it was not long before the shattered walls were deeply buried beneath their own débris and covered by the quick-growing tropical vegetation. The monolithic sculptures scattered about the courts and plazas remained entirely hidden from view by the thick veil that nature had spread over them. To-day all are brought to light again and stand exposed in the open, the delight of students and the marvel of the visiting world. In this condition they are unfortunately subject to the attacks of wind and rain, the wear by repeated cleaning, and injury by vandal hands. Nature, after disaster had fallen upon the city, spread over the ruins a mantle of protection, but to-day the explorer has exposed them to further ruin. No wall, howsoever strong, will stand exposure in the open in this climate for a single generation. The restored walls of the principal building of Quirigua, from 4 to 6 feet in thickness and not exceeding 12 feet in height, laid up in 1910 with Portland cement, are to-day in a state of ruin as complete as the original walls were when first brought to light by the School of American Archæology. In this state they are ready to welcome, as did the original ruins a thousand or more years ago, the quick-growing veil of vegetation.

The question of the future of these monuments thus becomes a matter of interest to the whole civilized world. So precious are they to history and science and so valuable as a material asset to the people of Guatemala, that steps will certainly be taken to shelter them from the dangers with which they are beset. Is it better then, considering impending obliteration, that they should have remained forever entombed in the forest? Certainly not, for the stage of civilization has now arrived in which the historic value of such monuments is appreciated, and their story, so far as archeological science can reveal it, will soon be written into the literature of the world. This record must be so full and lasting that should the works themselves entirely disappear the world shall still have, and for all time, the full advantage of the story. Future generations will, however, hardly excuse the present should no adequate steps be directed

toward the preservation of what remains of these masterpieces of ancient American art. Should the extraordinary upper surface of the dragon, shown in an accompanying illustration, continue as now exposed to the elements and to the wear that will come, what must we anticipate its appearance will be after the lapse of a thousand years? The strongly relieved features will be leveled with the general surface and the deep-set eyes lifted to heaven will, from the tears that fill them with every storm, be blind depressions in the roughly pitted surface of a great meaningless bowlder of sandstone. As soon as the work of exploration and record is completed the work of preservation, of covering in, should be taken up as a national obligation of the Republic in whose custody these monuments must remain.

A PREHISTORIC MESA VERDE PUEBLO AND ITS PEOPLE.

By J. Walter Fewkes.

[With 15 plates.]

INTRODUCTION.

The Mesa Verde, or Green Plateau, is situated in the southwestern corner of Colorado and was set apart by Congress from the Ute Reservation for protection of its prehistoric remains. Its form is oval, measuring about 42,000 acres, with an average elevation of over 7,000 feet above sea level, rising abruptly on the north side to 8,700 feet, over 1,500 feet above the plain. Its surface is cleft by deep, almost parallel canyons opening into the Mancos Valley on the south, between which are spurs of the mesa sloping gradually southward. In the canyons (pl. 2) are located the most remarkable cliff dwellings of the Southwest. The top of the plateau is dotted with mounds of earth and stone. The present article deals with one of these mounds, which was excavated and the exposed ruins repaired by the Smithsonian Institution, during the months of July, August, and September, 1916, at the request of the Secretary of the Interior, following a recommendation of the writer in his report to the latter on field work at Sun Temple in the summer of 1915.

Clusters of mounds composed of artificially worked stones and earth situated on the surface of the mesa have long been known, and from indications these piles of stones were believed to mark the sites of buildings. None of these mounds, however, had been opened, or their contents investigated. The plan of operations was to determine, by excavations, the character of the buildings concealed in them, and to interpret their cultural relations and significance. A cluster of mounds known as the Mummy Lake group was chosen as promising and advantageously situated for this purpose. The excavation of one mound of this cluster revealed a large building of a type new to the plateau.

The importance of the results of the work and their bearing on southwestern archeology may be better appreciated after reading what immediately follows. A portion of the area now known as

Arizona, Utah, Colorado, and New Mexico was inhabited in prehistoric times by Indians culturally unlike those of any other region of North America, and for that reason this unique territory bears the name Pueblo culture area. It is, in fact, the only aboriginal culture area where buildings have determined the name, being distinguished from all others mainly by architectural characters. This limitation of characteristic terraced communal houses to a geographical area leads us to associate climate or other conditions of that area with peculiarities of buildings, as cause and effect.

Of man when he first entered the Southwest, we know little save that his physical features show that he was an Indian. The time of his advent is in doubt. Considerable obscurity also exists regarding the direction whence Indian colonists entered this district, but there is no doubt regarding the geographical locality where Pueblo culture, judged from the character of buildings, originated. The immigrant clans that first peopled the Southwest are supposed to have come from people who built neither cliff dwellings nor pueblos, consequently this style of dwelling originated exactly where it is now found.

But the Pueblo culture must not be interpreted solely by peculiarities in buildings, for although it receives its name from architectural characters, there are influential factors that it shares with those of other tribes of Indians which are very important. One of the most noteworthy of these is the possession of maize or Indian corn as a reliable food resource. Agriculture is one of the corner stones of the Pueblo culture, as masonry is another. When man first entered the Southwest he knew little of the advantages of stone as a building material, for he built his hut of mud, sticks, or possibly of skins of animals. The North American Indian became a good stone mason as a result of a life in caves. Nowhere outside of the Southwest were elaborate buildings[1] constructed of dressed stone by the aborigines north of Mexico. Masonry and agriculture, then, are the primary factors that determined the essential peculiarities of Pueblo culture.

The Mesa Verde was set aside as a national park on account of its prehistoric stone buildings and monuments. While it presents rare facilities for a study of aboriginal architecture, it shares with other regions of the Southwest the condition that imperishable aboriginal buildings have survived from prehistoric times. Evolution of masonry in this region is a development which occurred in prehistoric times, or before the advent of the white man. No European ever saw an inhabited cliff dwelling on the Mesa Verde, and no article of European manufacture has ever been found in the undisturbed débris

[1] Stone walls and vaults were, of course, constructed elsewhere by Indians; cf. Mr. Gerard Fowke's article, Bur. Amer. Ethnol. Bull. No. 37, et al.

of the rooms. These cliff dwellings were abandoned before the Spanish conquest.

The inhabitants of the caves on the Mesa Verde were ignorant of hieroglyphs or letters, and therefore have left no written account of their origin and early history, although vague traditions are preserved by their descendants, especially among living Pueblos, as the Hopi. The most reliable data we now have to aid us in interpreting their culture are their buildings and archeological remains, or monuments, and minor antiquities, called artifacts, especially objects of burnt clay, that they have left behind. Their houses are the most significant.[1] As pointed out by Westropp, in referring to prehistoric and historic cultures of other races: "Architecture is the external form of their public life; it is an index of their state of knowledge and social progress."

One type of building characteristic of this culture is illustrated by Spruce-tree House and Cliff Palace, but this is not the only form. There are others, such as Sun Temple, brought to light in the summer of 1915, in which we find a building specialized for religious purposes.

Field work in the Mesa Verde during the summer of 1916 first revealed still another type differing considerably from the two preceding. This type, locally new, is known to ethnologists as a pueblo, commonly defined as a terraced community building constructed in the open or not attached to cliffs. It is a representative of many buried houses on Mesa Verde, and it is not too much to say that formerly there were as many buildings of pueblo type on top of the plateau as there were cliff dwellings in its canyons. Manifestly a knowledge of the Mesa Verde variety of pueblo is desirable, and a description of it will enlarge our conception of prehistoric culture in this locality. The object of the present article, then, is to make this known as a contribution to our knowledge of the aborigines of Mesa Verde.

The general condition and situation of mounds on the surface of the plateau will first be considered.

THE MUMMY LAKE GROUP OF MOUNDS.

One of the best known group of mounds in the Mesa Verde National Park is situated south of a reservoir called Mummy Lake. There is no good reason for calling this prehistoric reservoir a lake, for it is not a lake, and no mummies have ever been found in or near it. The term "Moki Lake," by which it is sometimes designated, is equally meaningless, but both names are so firmly fixed in literature that it is difficult now to substitute others.

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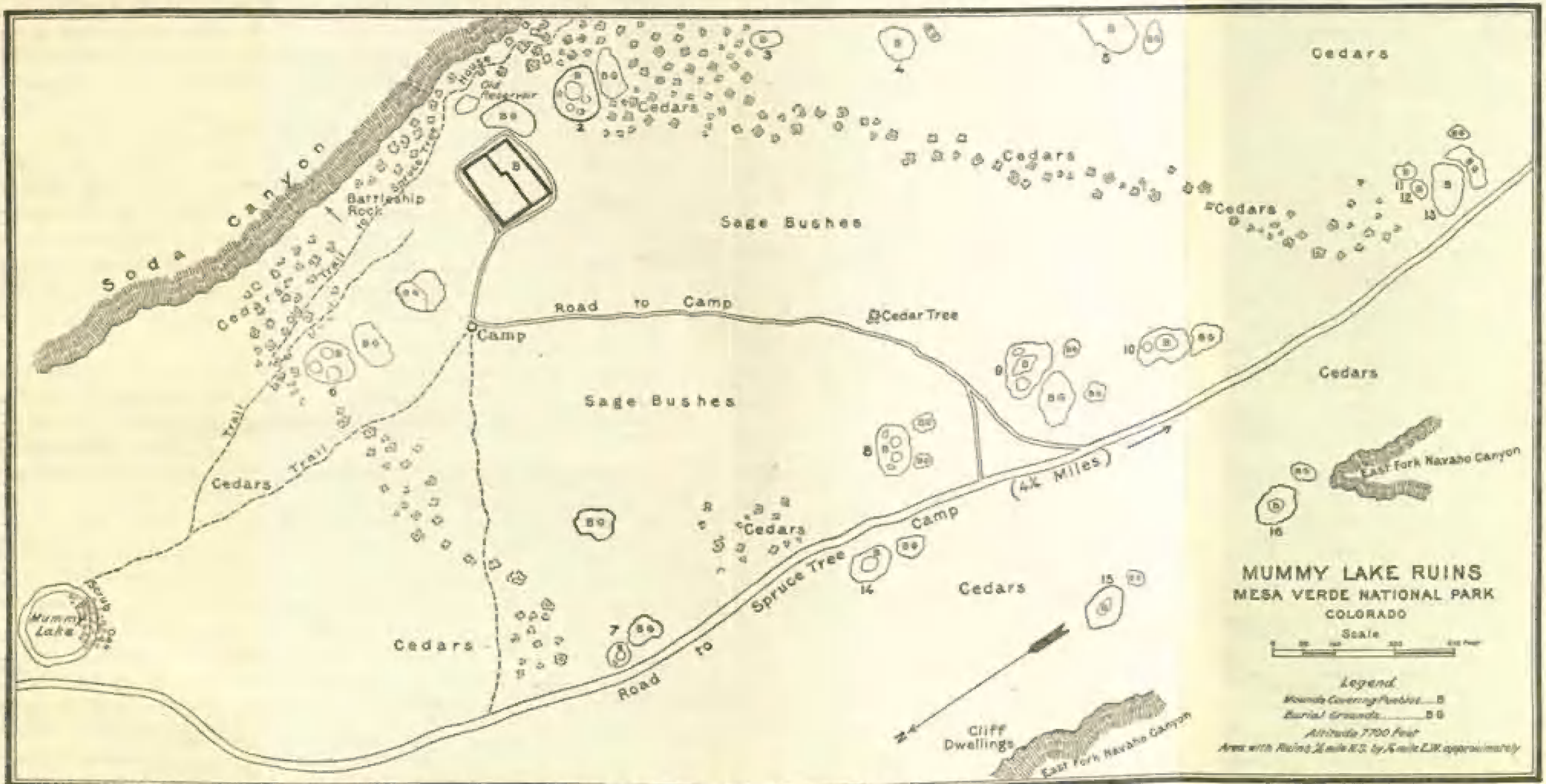
[1] Probably some writers on classical archeology would hardly consider cliff dwellings architectural forms.

The best description of this reservoir is the following, quoted from Baron Nordenskiöld's "Cliff dwellers of the Mesa Verde" (p. 74):

A structure of considerable size, which was probably utilized for purposes of irrigation, lies on Chapin Mesa, some kilometers above the great ruins and not very far from the slope into Montezuma Valley. A large depression 30 meters in diameter is surrounded by a low, circular wall 4.5 meters thick. Water was probably conducted to this reservoir from some neighboring gulch. Traces of a ditch which formed the connection have been observed north of the reservoir by Richard Wetherill. A view of the reservoir is given in figure 43, which, however, shows only a part of a low, ring-shaped mound overgrown with bushes, all that is left of the thick wall. Quite near the reservoir we find the ruins of a considerable village, but the walls are now leveled with the ground, leaving only huge heaps of stone to mark the site.

Mummy Lake, or Moki Lake (pl. 7, fig. 1), is an artificial depression surrounded by an oval or circular ridge of earth, in places outlined by double walls of stones suggesting rooms. Excavations at the base of these stones, however, show that their foundations do not extend far below the surface; but work thus far has not been sufficient to prove conclusively that there were not rooms on the periphery. Mummy Lake lies on the northern edge of a group of mounds where the slope of the surface of the plateau would seem to indicate that water could be readily drawn from it. It is probable that the farms of the ancients were situated between the pueblos of the Mummy Lake group, and that these farms were irrigated by water drawn from this reservoir by means of irrigating ditches. In the time that has elapsed since the Mummy Lake pueblos were deserted the reservoir, like the ditches, has been filled with wind-blown sand or soil, so that its depth has greatly diminished, and at present water remains in it only a short time. Probably in prehistoric days it contained a perpetual water supply of a purer quality than now, when it is fouled by cattle excrement and made impure by mud washed into it from the surrounding banks; and if such were the case the reservoir probably supplied the neighboring pueblos with drinking water, since springs in this neighborhood are remote and very difficult of access. For instance, at the bottom of Soda Canyon there is an unpalatable soda spring, a climb from which to the pueblo is very arduous. Another spring, at the head of the same canyon, now used for watering stock, is over a mile distant, while a third possible source of palatable water is near the head of Navaho Canyon, even farther away. There was a small reservoir, possibly communicating with the larger by canals, now clogged with sand at each mound in the group. One of these minor reservoirs is indicated on the map near the mound excavated.

A much worn trail extended from Mummy Lake to Spruce-tree House, just east of the house excavated, and between it and the



DISTRIBUTION OF MOUNDS IN MUMMY LAKE GROUP. SURVEYED BY C. STANSBURY.

rim of Soda Canyon. This trail, used by horsemen before the Government road was constructed, was probably an old Indian path of great antiquity, connecting the various pueblos of the Mummy Lake group with Spruce-tree House and Cliff Palace. A steep branch trail descends from it over the rim of Soda Canyon to the spring above mentioned, near which are mounds of ruins sheltered by Steamboat Rock. This trail may have been used by water carriers in prehistoric times.

The position of the mounds on the plateau near Mummy Lake were first designated on an excellent map of Mesa Verde, published by the United States Geological Survey. It is evident from this map that the cluster of mounds near Mummy Lake is only one of several groups; for instance, from the rim of Soda Canyon, looking north and east, four similar clearings can be seen, in each of which are several artificial mounds, all of which have the same general form and are covered with sagebrush.[1] No regularity is noted in their arrangement (pl. 1), but they vary in size and shape, all appearing to have, as a common feature, a central depression, which, judging from that excavated, indicates a large kiva. We find superficial evidences of rectangular and oval houses, and in one instance the building under the mound may have a D shape. Fragments of walls projecting above the ground are absent in all cases, but in one or two instances the direction of the buried wall can be followed for a few feet by surface indications.

As these communes or clusters of small pueblos are more conspicuous in clearings than among the thick cedars, the question naturally arises whether they were built before the cedars grew or whether man burnt or otherwise removed the trees of the forest before he laid their foundations. The author inclines to the belief that the clearings were made by the hand of man, and that cedars were growing on the mesa when man appropriated it for his habitation or for planting. When once removed the constant tramping of people would certainly prevent trees from again growing on the cleared areas. At the time the buildings were inhabited they were surrounded by farms cleared of underbrush, and it appears from the amount of sand and soil filling the rooms of the pueblo that the wind played a great rôle in transporting sand to the mound from the surface of the bare earth. Sagebrush or trees would tend to anchor the soil and prevent its blowing away, which implies that the sagebrush has grown since the fields were no longer cultivated. As shown on the map (pl. 1), one or two of the smaller mounds of the group lie outside the clearing or in the cedars, a few of which trees

[1] This relation of mounds to sagebrush covered clearings is discussed by Dr. Prudden, Amer. Anthr., Vol. 16, No. 1, 1914.

also appear on top of the mounds. It may be mentioned that there is no evidence of a sagebrush clearing in the area about Sun Temple, which supports the theory that it was unfinished and uninhabited. Had Sun Temple been a domicile we would expect what we find in the neighborhood of Mummy Lake, some evidences of cultivated fields.

The sagebrush clearings are very fertile and throughout the summer months are carpeted with flowers, the most abundant of which is the "Indian paint brush"; later these plants, rare or unknown among the cedars, are succeeded by various species of asters. On account of the large number of flowering plants in the sagebrush clearings, unusually tame humming birds are very common, but with the advent of autumn they likewise vanish and the leaves of the scrub oaks change their colors and the mesa top is brilliantly painted with bright yellow and red. Almost everywhere, especially over the surface of the mounds, fragments of pottery are abundant, and here and there on the level surface between the mounds are remains of low stone walls, suggesting pit-houses,[1] gardens, or irrigating ditches.

There are several clusters of mounds visible from near the Mummy Lake group. On the side of Soda Canyon there is an elevated outcrop, called Steamboat Rock, which protects a cluster of mounds, with sunny southern exposure, from the north winds. In a clearing on hills near the head of Soda Canyon there are also mounds or sites of former pueblos. It is important to note that these groups of mounds always occur in sagebrush clearings; their occurrence among cedars, where they are smaller, is common but less conspicuous. The many flowers blooming in these localities show that the land is rich, and it is probable that Indian corn could still be grown on the Mesa without artificial irrigation.

MOUND EXCAVATED.

The mound in the Mummy Lake group chosen as a type for excavation to determine the character of Mesa Verde pueblos is situated four miles and a quarter due north of Spruce-tree House, and is one of sixteen scattered at intervals on both sides of the Government road. It stands about an eighth of a mile east of this road, a few steps from the rim of Soda Canyon. This pueblo (pl. 4) might be called Far View House, for the distant southern outlook from it is very fine and has been commented upon by almost every visitor.[2]

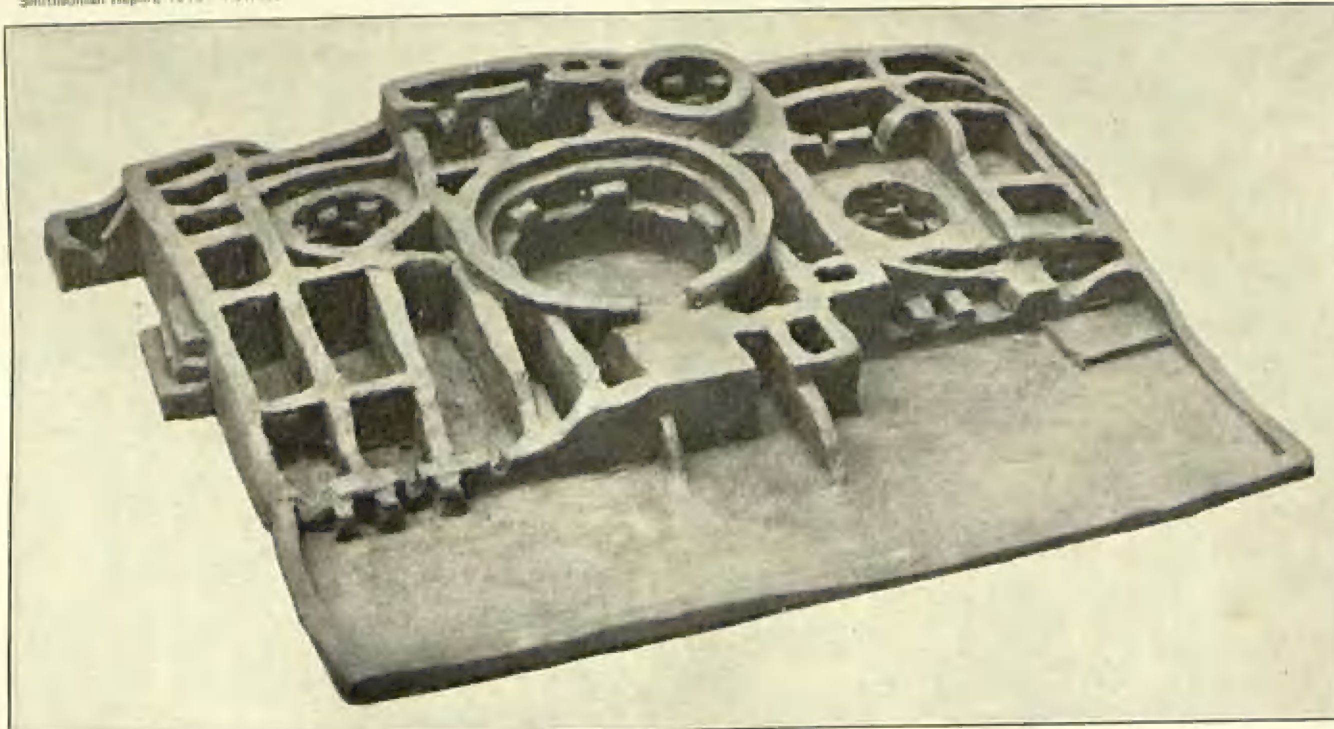
[1] It would be futile in the present state of our knowledge to speculate on the number of the inhabitants of these buildings long ago fallen into ruins, if simultaneously inhabited. There is no doubt it was large, much greater than suspected by early investigators. We are on the threshold of a great research and every year's field work will advance us a step in deciphering the history of this interesting race.

[2] The name Far View House, which calls attention to this fact, was suggested by one of my workmen, Mr. Jason Myers.

TYPICAL MESA VERDE CANYON, LOOKING SOUTH.

FAR VIEW MOUND FROM SOUTH SIDE BEFORE EXCAVATION. PHOTOGRAPH BY FRED JEEP.

SOUTH SIDE OF FAR VIEW HOUSE AFTER EXCAVATION. PHOTOGRAPH BY GEORGE L. BEAM.



MODEL OF FAR VIEW HOUSE. (FOR DETAILS CONSULT FIG. 1.)

From its highest rooms the corners of the four States of Utah, Arizona, New Mexico, and Colorado—the only case in the country where four States meet in one point—can be seen far to the southwest. Sleeping Ute Mountain, Ship Rock, once called the Needles, and distant mountains of Arizona, rise on the horizon to the south and west. In the less distant foreground, beyond a forest of cedars, one can trace several important canyons of the Mesa Verde, among which may be mentioned Navaho, Mancos, and Soda. When the wind is favorable, the flag at Spruce-tree camp can be seen as a speck waving above the trees; the course of Spruce-tree Canyon can be traced without difficulty through its whole length. The surface of the land south of the ruins is covered with a dense forest of cedars and piñon trees sloping to the south. Looking back from the well-known tower at the head of Navaho Canyon or across country from the fine ruin, Spring House, one could make out the workmen on the ruin, with a good glass. Not many feet (80) from the southwest corner of the court there is in view a large mound pleading for excavation which may have an interesting story to impart regarding aboriginal culture. Two mounds in the group are situated in the cedars beyond, and a third, of large size, lies just south of the edge of the sagebrush clearing. The site of the pueblo is the most prominent one in the southeast corner of the area, and in a way this pueblo may be said to dominate the others. It was probably the largest, the most populous and important.

When excavation work was begun, the entire surface of this mound, like all of the group, was covered with sagebrush (pl. 3) and, like them all, showed a deep circular depression in the interior strewn with stones and débris. Some seeker after curiosities had dug a shallow trench on the highest point of the north side, revealing a fragment of a well-made wall and the sides of a doorway. From this a trench had been dug across the mound to what was eventually found to be the south side. This excavation had not determined the form, size, or height of the building, and probably did not reward the workmen with the small objects they sought.

Almost every visitor to the pueblo while the excavation was in progress remarked on the quantity of débris that filled the rooms and naturally asked whence it came. Many visitors were sure it indicated a great age; that a long time had elapsed to fill the rooms. The writer has also given much thought to this condition and concludes that this alone does not prove a great antiqity. It is difficult to explain this condition and to draw conclusions therefrom, but an examination of the arrangement or stratification of débris in the rooms is significant. For several feet below the surface the débris consists mainly of fallen stones mixed with adobe, resulting from the overturned tops of the walls. Penetrating deeper or below

this stratum, soil free from stones was found. This material, identical with the sand of the plateau, appears to have been blown into the rooms or brought from the surrounding fields by wind storms. The accumulation of débris due to falling walls and the addition of wind-blown sand would progress very rapidly as long as the wall projected above the ground, but would then cease. That time might be measured by centuries, certainly not by millenniums. Lower still occurs a layer of ashes with fragments of charcoal, a "pay dirt" in which artifacts are common. This is mixed with adobe, evidently remnants of plastering. Deeper sometimes follows another layer of sand or an æolian deposit; a sequence not uniform and not the same in thickness in all rooms. Evidently some of the rooms

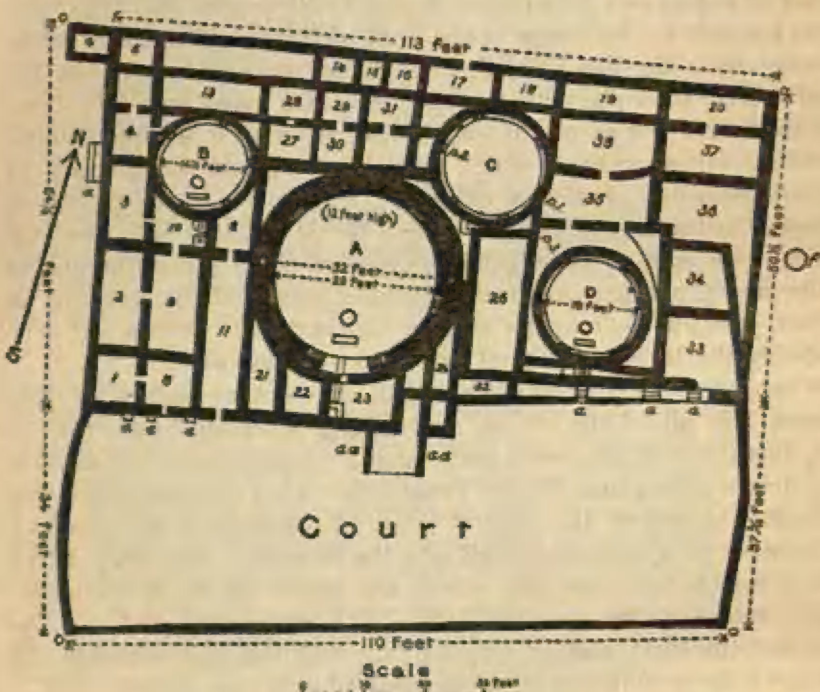


FIG. 1.—Ground plan of Far View House. Mesa Verde National Park, Colorado.

had been deserted and the sand accumulated to a depth of 2 or 3 feet, after which they were reoccupied and foundations laid on the sand, the new walls having been constructed to the height of the adjoining walls on this foundation.

GROUND PLAN OF BUILDING.

The arrangement of rooms reduced to a ground plan is seen on figure 1. The lowest story of the main building has 40 secular rooms and four ceremonial chambers or circular kivas. A few of the secu-

lar rooms have not been excavated to their floors. The majority of these are arranged in two tiers on the north and west sides. They are two-storied; the floor beams of the second story, which are rafters of the first, were found and left in place. The row of rooms north of kiva A likewise show evidences of the existence of a third story, so that it may be said there were about 50 secular rooms in the building.

All the secular rooms on the west side were completely excavated, and earth was removed from all kivas. The court or dance plaza is situated south of the main structure and is inclosed by a low wall measuring 110 feet on the south side, 37½ feet on the east and 34 feet on the west side.

The peculiarity of this pueblo consists of a large central circular kiva, around which are grouped secular rooms, to which are added smaller circular kivas. This central room recalls a tower, but, unlike some of the towers, this and the smaller kivas have pilasters attached to the walls for support of a vaulted roof. The great size of the central kiva suggests that the room was not limited to one clan: it points rather to a fusion of clans forming so intimate a union of several families that the room may no longer be considered as limited to men of one clan, but the meeting place of a fraternity of priests, drawn from several clans. The formation of such a fraternity is an advance, sociologically speaking, upon what we find indicated by the small clan kivas of cliff dwellings and implies more recent construction.

The regularity of the secular rooms, as shown in plate 5, strikes the observer at first sight. The partitions separating these rooms run north-south and east-west and are continuous through the pueblo. No such regularity is found in cliff dwellings, although it is a marked feature of pueblo ruins along the Chaco and elsewhere. Inhabited pueblos as Zuñi, Walpi, and others show this character only to a limited extent.

The rooms of this pueblo are consolidated into a rectangular form with straight walls broken on the south. The building is oriented approximately to the cardinal points, and terraced to secure sunny exposure on the south side. The method adopted by the Mesa Verde people in orienting their buildings, as Sun Temple, seems to have been followed at this pueblo, and reveals a knowledge of solstitial sun rising which is instructive. The sun priests of the pueblos had, of course, no compass and probably the polar north was unknown to them. Their north, west, south, and east, as with the Hopi, are not the same as ours and the line of the south wall of Sun Temple was determined by the position of the sun. It was not made haphazard, but was carefully thought out and determined by astronomical observation before the foundation was laid down. At the

autumnal equinox theoretically the sun rises in the east and sets in the west. In other words, sighting from the shrine along the so-called south wall on that date we ought to see the sun rise on a continuation of that line, if the wall extended exactly east and west. Observation shows that such is not the fact; the south wall does not extend exactly east and west. On the morning of the 21st of September, in company with several others, the writer determined this by observation, and found the line of the south wall if extended would touch the point of sunrise on the horizon a little more than 20° north of the extended line of the so-called south wall.

The same is true at sunset as viewed in the opposite direction as observed by my friend, Mr. T. G. Lemmon. The sun on that date sets about 20° from the extended line of the so-called south wall, which, if projected, would touch the point of sunrise at the summer solstice. This is so exact that the builders of Sun Temple probably determined the direction of the wall by observation of the sun as seen from the sun shrine at that solstice. The point of summer solstitial rising of the sun, as observed on the horizon, as well as sunset in midwinter were cardinal points among them, as among the Hopi, and determined the lines of their temple devoted to sun worship. It seems to have been in somewhat the same way that the orientation of the pueblo at Mummy Lake was determined, but as the south wall is more irregular and the building more patched upon this side, it was not as easy to make observations there as at Sun Temple, but it was possible to use the north wall for that purpose.

Inasmuch as some of the highest walls had been reduced in altitude by the fall of their tops there had accumulated around their foundations a mass of detached fragments. The remains of fallen walls were especially extensive along the north wall, and the removal of this material was a work of considerable magnitude. Scrapers and stone boats were used for that purpose but the wall itself was laid bare by hand. The funds appropriated for this work were insufficient to permit the removal of this mass to a considerable distance to make the desired grading, but an automobile road was constructed around the ruin so that it can be visited with little inconvenience.

The excavation was begun on the northwestern corner of the mound (pl. 6), which later proved to be a small square room (pl. 6, fig. 3) annexed to this angle of the building. It was found that the greater part of the northern wall had been reduced to about 6 feet in height, and that the partition walls of several rooms formerly attached to it had been shattered. The east wall (pl. 6, fig. 4) was in somewhat better condition, but inclined so much outward that it was considered advisable to construct a buttress to hold it up. The south wall (pl. 8, figs. 1, 2) was irregular and much

1. NORTH WALL, FIRST STAGE OF EXCAVATION. PHOTOGRAPH BY E. A. WEIL.

2. NORTH WALL, SECOND STAGE OF EXCAVATION. PHOTOGRAPH BY E. A. WEIL.

3. NORTH WALL, COMPLETELY EXCAVATED. PHOTOGRAPH BY E. A. WEIL.

4. EAST WALL, AT NORTH END. PHOTOGRAPH BY E. A. WEIL.

1. MUMMY LAKE, LOOKING EAST. PHOTOGRAPH BY MRS. C. R. MILLER.

2. WESTERN END OF SOUTH WALL, PARTIALLY UNCOVERED. PHOTOGRAPH BY MRS. F. W. CHINKSCALES.

3. NORTHWEST ANGLE, COMPLETELY EXCAVATED. PHOTOGRAPH BY J. WIRSULA.

1. SOUTHEAST ANGLE OF MOUND BEFORE EXCAVATION. PHOTOGRAPH BY FEWKES.

2. SOUTHEAST END BEFORE EXCAVATION. PHOTOGRAPH BY FEWKES.

1. MOUND FROM SOUTHWEST BEFORE EXCAVATION. PHOTOGRAPH BY J. WIRSULA.

2. MASONRY OF NORTH WALL. PHOTOGRAPH BY MRS. F. W. CHINKSCALES.

broken down; here (fig. 1, *a, a, a,*) buttresses were necessary. Near a recess situated midway in the length of the wall props (*aa, aa*) had been constructed by the aborigines to hold it from falling while the building was still occupied. The east wall also leaned considerably and had to be repaired. There is fine masonry in certain portions of all these walls (pl. 9, fig. 2; pl. 10, fig. 2), but on the whole it was inferior to that seen at Sun Temple.

As the number of rooms is greater than in Sun Temple, the work of excavation was more laborious than in the preceding summer, the shattered walls necessitating more repair work. The walls of a few rooms had been constructed on sand foundations, indicating that these rooms had been deserted and reoccupied. Other walls showed evidences of having been repaired while rooms were still occupied. The writer had no doubt that the building was a habitation, as many objects of household use were found at all depths from the very inception of the work.

The main north wall, exclusive of a small room of unknown use on the northwest angle, measures 113 feet from the northeast to the northwest corner, and was formerly about 20 feet high. The east wall extends 50½ feet and the west wall 64½ feet, both averaging about 10 feet high. There is a court surrounded by remnants of a wall rising a foot out of the ground on the south side. This wall rises highest where it joins the southeast and southwest angles of the main building. About midway in its length there is a recess in the south wall, evidently intended to hide the entrance ladder, resembling a similar recess at Sun Temple and Cliff Palace. The angles of this recess and the accompanying wall show good masonry; the corners inclined slightly outward, not being properly bonded to the remaining wall. The masonry throughout is fair but shows all the faults of cliff dwellers' work; joints unbroken, corners not bonded or properly tied to the other walls. The adjoining surfaces of the superposed stones were not flat, the mason relying upon slivers of stones, set in mud, to fill the intervals between them. He so multiplied the number of these stones that it weakened the walls, for the mud in which these were inserted easily washed out and the walls became unstable in course of time, notwithstanding they are thick, though in some cases the walls are narrow, not more than a few inches wide. Marks of human hands, and in a few instances impressions of corncobs were seen in the pointing of the walls—the latter perhaps accidental; no marks of a trowel were found.

Large, flat, thin, unworked stones set on edge occur at the southwest inner corner, where the wall surrounding the court joins the south wall of the main building. These stones are of such a size that they may be called megaliths, as it would require three men to handle one of them. Their insertion in the wall is regarded as a survival

of a stage in southwestern masonry antecedent to the employment of hewn stones.[1] As a rule there were no stones in the wall construction that could not be carried by a single pair of hands.

A majority of stones show evidences of artificial pecking or dressing on their surfaces, a few being smoothed by attrition. Plastering as a rule is absent, but appears in layers over the surfaces of the small kivas. Its absence on the rectangular rooms and presence on the kiva walls suggests that it was protected by the vaulted roofs of the latter, which fell long after those of the former.

There are many stones with incised decorative figures, possibly "mason marks," different from those of Sun Temple set in the inner walls of the building. The spiral (fig. 2), representing the serpent of the water, occurs several times. The same figure was noticed on a round room lately discovered a mile from Spruce-tree House and on a round tower in Cannon Ball ruin, near the McElmo. One of these spirals was accompanied by radiating, peripheral, parallel lines, suggesting a figure of the feathered snake. Several of the more striking figures from stones fallen or still remaining in the walls are shown in the accompanying figures (fig. 3). They resemble designs on black and white pottery ware.

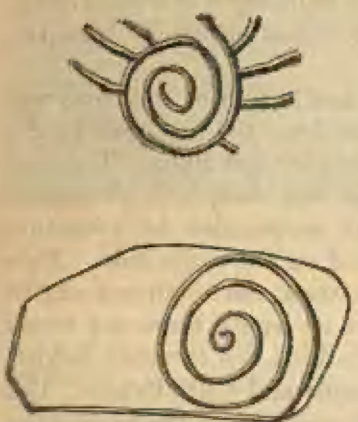


FIG. 2.—Serpent symbols incised on rocks in masonry.

Various interpretations have been suggested to explain these figures, some of which are fanciful; there is no reason to doubt that they were primarily decorative, but they may also be symbolic. The complicated form of several incised figures suggests something more than meaningless efforts at embellishment, but it is too much to hope that they have any value as inscriptions. Although these designs are regarded as decorative, the limitation of the spiral to round rooms, towers, or kivas hints at a deeper significance. There is an obscure legend among the Hopi that circular kivas are connected in some way with snake ceremonials, and the association of the spiral sign and circular rooms seems to support, in a way, this idea.

TYPES OF ROOMS.

The rooms have two shapes, circular and rectangular, with triangular recesses between them, which are inclosures, not rooms. The circular rooms are evidently kivas or ceremonial chambers,

[1] Jackson describes an extensive wall of a ruin in Montezuma Canyon constructed in this manner.

1. SOUTHWEST ANGLE OF MOUND BEFORE EXCAVATION. PHOTOGRAPH BY FRED JEEP.

2. NORTH WALL, LOOKING WEST. PHOTOGRAPH BY FRED JEEP.

1. SOUTHWEST ANGLE, PARTIALLY EXCAVATED. PHOTOGRAPH BY J. WIRSULA.

2. SOUTHWEST ANGLE, PARTIALLY EXCAVATED. PHOTOGRAPH BY J. WIRSULA.

evolutions of the men's rooms of an early time. The four circular kivas are identical in form and architectural features with similar rooms in cliff houses, which identity may be explained by the fact that religious buildings preserve archaic forms. They are, as a rule, better constructed than secular dwellings. The secular rooms vary considerably, but have a general likeness in form, size, and position of doorways.

The majority of rooms found in Mesa Verde cliff houses fall into the following types:

1. Ceremonial rooms or kivas: These are circular,[1] sometimes D-shaped, generally subterranean. There are two varieties of kivas—those that formerly had a vaulted roof and those with a flat roof. Banquettes and pilasters, fire holes, ventilators, and deflectors are present in the former.

2. Storage rooms: These are generally situated on the ground floor or below the others. They are without windows and were apparently entered from the roof; but often with side entrances communicating one with another. The largest number of rooms in cliff house are for storage of corn and other possessions. This type may be regarded as one of the oldest.

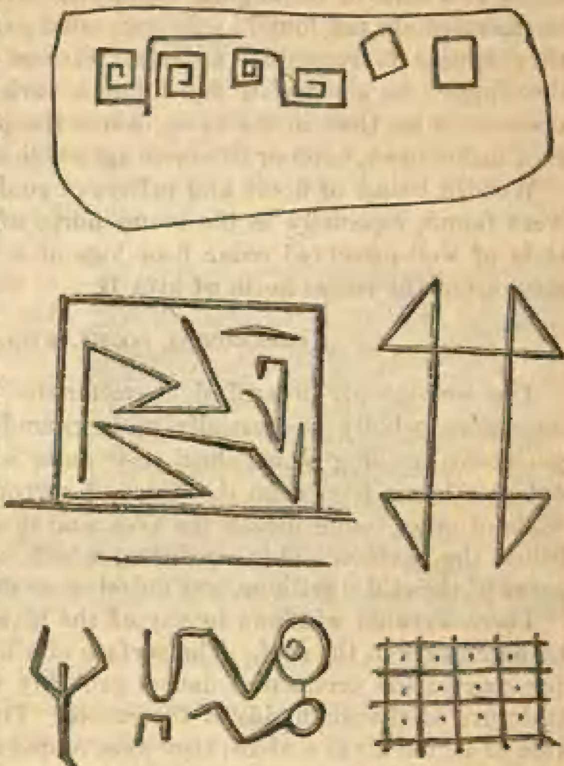


FIG. 3.—Incised figures on masonry.

3. Sleeping rooms: This type is the nearest approach to a living room, but is rarely specialized for this sole use.

4. Milling rooms: In these inclosures, often covered, but generally without roofs, we commonly find a mill for grinding corn, and sometimes a fireplace for frying paper bread or "piki." A room for this latter use is sometimes differentiated from the milling room.

[1] There is said to be a rectangular kiva in one of the undescribed cliff dwellings of the park.

Cooking was done out of doors, either in a secluded corner of the court or on housetops; several rooms have corner fireplaces.

5. Circular rooms: These rooms are sometimes lookouts, but as often dedicated to ceremonials.

In addition to those mentioned above, there exist also inclosures of various forms, especially where we have circular kivas set in the midst of a mass of rectangular chambers. All types of rooms above enumerated are not found in the excavated pueblo, but when present they appear to reproduce essential features characteristic of cliff dwellings. As a rule, all the different varieties are larger in the open-air ruins than in the caves, where the protection of a natural roof makes open, outdoor life more agreeable and convenient.

Wooden beams of floors and rafters of roofs, very much decayed, were found, especially in the rooms north of the large kiva. The ends of well-preserved cedar floor logs of a basal room protruded into one of the rooms north of kiva B.

CEREMONIAL ROOMS, KIVAS.

The well-known prescribed characteristic of cliff-house kivas—depression wholly or partially underground—is preserved in the pueblo by building rooms about their outer wall. The kiva floor is not at a lower level than the floors of surrounding rooms, but the walls of other rooms inclose the kiva, and thus sink it to all intents below the surface. This condition, which occurs in some of the kivas of the cliff dwellings, was universal at the Mummy Lake ruin.[1]

There were no windows in any of the kivas, and entrances were by hatchways in the roof. The surface of a kiva roof was too small for courts; the ceremonial dances probably took place within the inclosure on the south side of the pueblo. The method of construction of all the kivas is alike; they were roofed the same way (fig. 4).[1] The central kiva is much larger than the remaining three, suggesting the name "assembly kiva," it being possible that instead of serving as the ceremonial room of a single clan, it was the room of a priest fraternity composed of several clans, or even an assembly place of all the people of the pueblo, reflecting a more advanced sociologic condition than in cliff houses and more like that found among pueblos of the Rio Grande, where we have but two kivas for the whole population.

As shown on the accompanying ground plan (fig. 1), the three small kivas are constructed on the same general plan as the kivas of Spruce-tree House and Cliff Palace. All have six pilasters for

[1] The Hopi kiva is constructed underground because tradition declares that it symbolically represents the underworld from which the ancients emerged into the present world. This esoteric prescript was also religiously observed by cliff dwellers so rigidly that when necessary the floor was excavated in solid rock.

the support of a vaulted roof, and in some of these kivas the charred remnants of the rafters still remain. The most eastern and northern kivas (B, C, D) show evidences of a conflagration. The amount of smoke on the plastering of the walls is greater than would appear on the plastered walls if the roofs had not been burnt; moreover, the surfaces of the walls are colored bright red. The central kiva, A (pl. 12), is constructed on the same general lines as are the small kivas. It likewise had a vaulted roof supported on pedestals, a fireplace, ventilator, and deflector. No ceremonial opening or sipapu[1] was detected in the floor of this kiva, which is also true of B and C; kiva D has the neck and part of the handle of an earthen cup set in the east wall forming a hole just below the level of the top of the banquette. When seen from the top of the room this insertion resembles a metallic pipe, for which it is often mistaken by visitors. Whether or not the opening represents a ceremonial orifice is not known, but if it does this is the only instance known to the writer where a sipapu of this kind is found in a side wall and not in the floor between the fireplace and the kiva wall opposite the deflector.

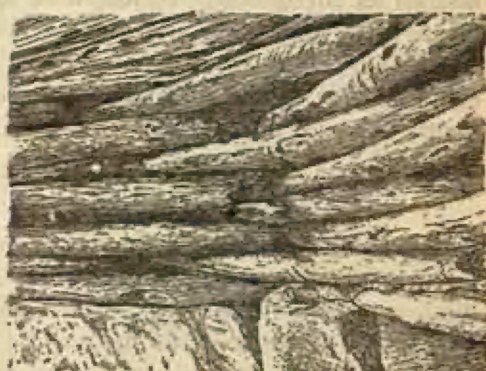


FIG. 4.—Beams of kiva roof resting on a pilaster.

The construction of a vaulted roof over a room 32 feet in diameter was certainly a feat for stone-age masons that is worthy of more than passing notice. Naturally the writer could not believe this possible without the introduction of upright supports resting on the floor near the middle of the room. No evidence of such verticals was found and no depressions in the floor for their insertion about the fireplace were observed. It seems, therefore, that the masons accomplished the vaulting by logs resting on peripheral pedestals (fig. 4), as in smaller kivas.[2]

The cliff dwellers are said to have been unacquainted with the arch and keystone, but they were not unfamiliar with the so-called Maya

[1] The opening in the kiva floor called the sipapu is still used in Hopi ceremonials, through which to communicate with the underworld where a ghostly company of the dead are supposed to live engaged in the same occupations as when alive.

[2] The method of construction of a vaulted kiva roof in a Mesa Verde cliff house is shown in a restoration at Spruce-tree House, taken from a portion of a roof still preserved in Square Tower (Peabody) House. The illustration in the text above was drawn from a photograph of the last mentioned by Mr. Gordon Parker, supervisor of the Montezuma National Forest.

arch. The masonry about the entrance into the ventilator (fig. 5) of the large assembly kiva, A, recalls this form of arch and is unique in the construction of Mesa Verde ruins. It consists of a flat slab of stone forming the top resting on other stones, each set a little back from the one above it, making a form of arch, but not the keystone type, which, so far as known, is absent in Mesa Verde buildings.

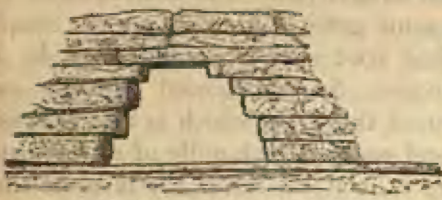


FIG. 5.—Maya arch in flue of kiva A (Schematic).

It may be said that on the whole the best masonry is found in the kiva walls, as is true in other types of buildings. The indications are that the large central kiva, A, is the oldest and that the other three, embedded in surrounding rooms, were later added to its outer walls. Changes in the walls and reconstruction of sections of the same were made after the original foundations were laid. This is especially noticeable in the position of the supports of the roof. Evidently the roof of the great kiva fell in before those of the smaller.

SECULAR ROOMS.

Besides the circular kivas this pueblo has many chambers which were secular in character, crowded about the ceremonial rooms. Among these the rectangular form predominates, although the intervals left between some of their walls and the outer kiva walls are inclosures of triangular or other shapes (see pl. 13). These recesses often have doorways but were not used as rooms, as is also indicated by the fact that the wall is jagged and destitute of evidences of chinking or plastering.

It may be seen, in the ground plan, that there are no courts or open passageways running between the rooms in the pueblo, and that the partitions are made compactly, forming a solid mass of buildings.

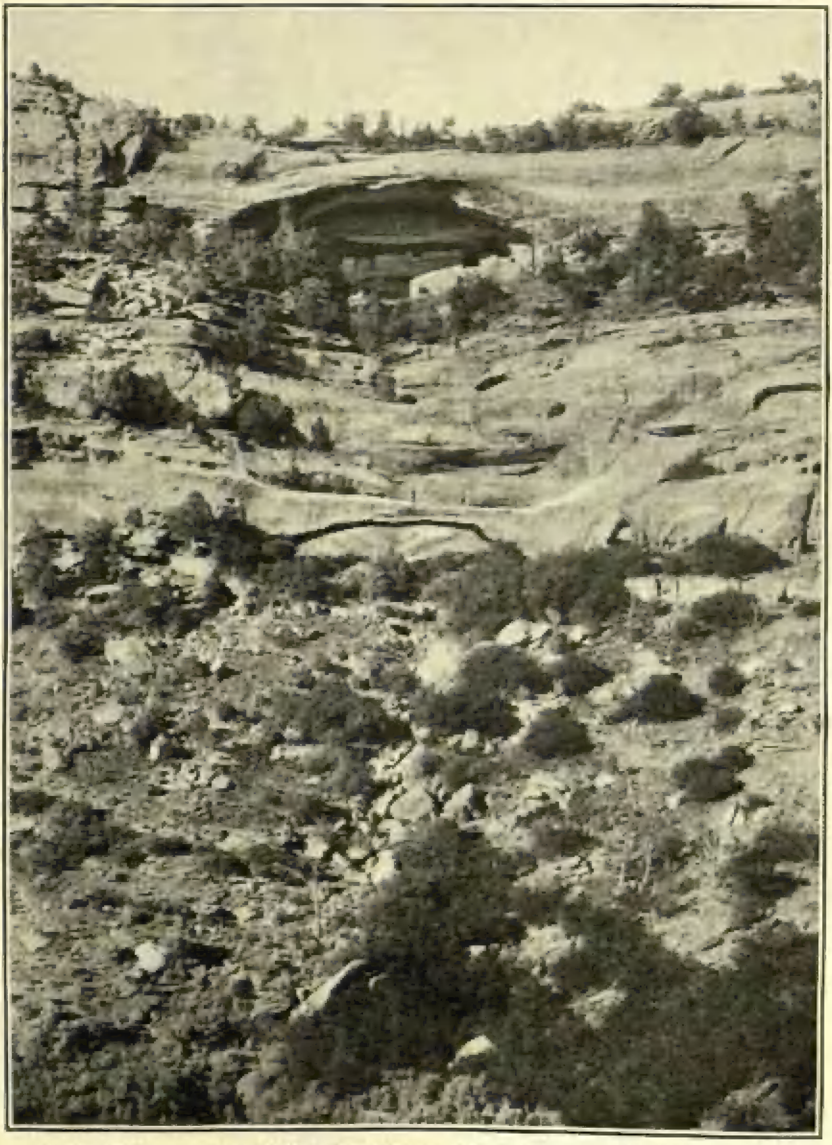
The rooms, as a rule, are larger that those of cliff dwellings. Their entrances are higher and broader, generally rectangular, but there are two doorways situated back of the large kiva, apparently in a third story, which are T-shaped like those in cliff houses, opening out over the roof of this kiva. There are no external, lateral doorways in the north, east, and west walls, and but three instances where rooms open directly on the court through the south wall. The evidences of a third story are confined to the north side, which suggests a terrace to the south; but as all the rooms are not excavated it is not possible to determine whether or not three-storied rooms are limited to this section or how extensively a terraced form characteristic of a large pueblo was followed. The smoke on the

CENTRAL KIVA, SHOWING MOUND 2 BEYOND WAGON, LOOKING SOUTH FROM P. 2, ON GROUND PLAN, FIG. 1. PHOTOGRAPH BY T. G. LEMMON.

CENTRAL KIVA, LOOKING WEST FROM P. 3 ON GROUND PLAN, FIG. 1. PHOTOGRAPH BY T. G. LEMMON.

1. ROOMS SOUTHWEST OF KIVA A, FROM SOUTHWEST ANGLE. PHOTOGRAPH BY T. G. LEMMON.

2. SOUTHEAST ROOMS, FROM KIVA D TO SOUTHEAST ANGLE. PHOTOGRAPH BY T. G. LEMMON.



SPRING HOUSE, SHOWING NATURAL BRIDGE. PHOTOGRAPH BY GEORGE L. BEAM.

walls of several rooms above corner fireplaces, the abundance of household utensils, as pottery and other objects, show that the pueblo was once inhabited and that people dwelt in the buildings many years.

Nowhere is the plastering so well preserved as in the walls of kivas between the floor and the level of the tops of the pilasters. The stratification of this plaster recalls a custom among living pueblo people. It is customary annually in February for the Hopi girls to replaster all the kivas, an episode which forms a part of lustral rites that pervade the Powamu or purification from the evil god who has control of the fields in winter. A somewhat similar ceremony may have taken place in the Mesa Verde pueblos. The successive layers of smoked clay are indicated on sections of plaster from the wall of kiva B, and number at least 20. This kiva had been plastered 20 times.

On the floor of a second-story room, below those in which are the T-shaped doorways, were found slabs of stone set upright forming a grinding bin, in which a grinding stone or a metate was found in place. In the west corner of the same room the walls showed marks of smoke and an arrangement of stone slabs indicating a fireplace.

REPAIR AND PRESERVATION OF WALLS.

As has been pointed out in an account of Sun Temple,[1] the destruction of the walls of ruins standing under the open sky is largely due to violent rains or the infiltration of snow water and its subsequent freezing. To obviate this destructive agency the tops of all walls in Sun Temple were covered with Portland cement laid on adobe with a foundation of broken stones or rubble. This precaution has been found to accomplish the required results. Not a rock of the walls of Sun Temple fell from its place in the winter of 1915. The tops of the walls of the kivas of the pueblo excavated during the summer of 1916 were treated in much the same way, except that a coarse groat was added to sand in the cement.

In the repair work at Far View House it was necessary also to add a few courses of masonry to the tops of the exposed walls, and to prop up the outer walls on the west and south side with buttresses. The largest of these buttresses appears as steps on the west outer wall, which leaned so much that it certainly would have fallen as soon as uncovered if not held up in this way. This buttress was constructed about fallen walls.

To prevent the partition walls on the west tier of rooms from falling when their supports were removed their west ends were tied

[1] Excavation and Repair of Sun Temple, Mesa Verde National Park. Department of the Interior, 1916.

with new masonry to the inner side of the west wall. This was done with adobe and will be effective for a few years only. The tops of all walls ought to be covered with Portland cement.

In order to show the extent of the repair work on the tops of the walls the added courses were set a little back of the original wall, a method adopted from European archeologists.

Opinions may differ as to the amount of new masonry allowable in the repair of our ancient ruins, but the fact still remains that unless the walls are protected they will fall in a few years into piles of stone. To prove that statement one need only inspect excavations where no repair work has been done.

The amount of the appropriation was so small that it was not possible to treat all the walls in the same manner, much to the writer's regret.

CEMETERIES.

Although no excavations were attempted for the sole purpose of finding human bones,[1] an almost complete skeleton of an adult was excavated from kiva B, about 6 feet below the surface. This skeleton was without pottery and showed no evidences of having been previously buried with pious care, the distribution of the bones suggesting a secondary hurried interment, possibly some time after the pueblo was deserted. Skeletons were not found under the floors.

A low mound in which the dead were systematically buried, called the cemetery, is situated near the southeast corner of the building, a few feet from the east and south walls. As with the cemeteries of all members of the Mummy Lake group, this mound had been trenched and its contents removed many years before the writer began work, evidences of broken mortuary vessels left by the workmen being abundant over the surface. A few skulls and larger bones were removed from the cemetery south of the pueblo, but there remained with the dead no whole pieces of pottery, so successfully had the graves been rifled by my predecessors. The bodies found were flexed or bent in a contracted position.

MINOR ANTIQUITIES.

As stated above, the two factors available for a knowledge of the history of a people ignorant of letters are buildings and smaller movable antiquities, such as pottery and other objects. We have already treated the former factor, and there remains to be considered the latter, embraced in the term "minor antiquities." So far as relics go, information drawn from these supports the conclusion

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[1] It may be well to call the reader's attention to the fact that this article is intended to deal only with cultural features upon which the pueblos have been differentiated from other stocks of American Indians.

derived from architecture, but a consideration of their significance in all its bearings must be left to a more exhaustive technical discussion than is here possible.

During the removal of earth from the rooms a large number of these small objects were found, but in the present paper it is impossible to do more than consider a few of the many relics excavated in the course of the summer. The majority of the objects came from the floors and in débris of the rooms, but a number were picked up outside the walls. These objects are practically identical with those found in cliff dwellings, indicating a similarity of culture notwithstanding there is a noticeable variation, especially in designs used in pottery decoration. Many duplicates of stone objects, as metates, manos (hand stones), pecking stones, mortars, and the like, were gathered together and left in a conspicuous place where they could be seen by visitors, but the majority, and all unique objects, were brought to Washington to be deposited in the National Museum, as required by law.

Several of the smaller stones with incised figures were set in cement on the south wall about midway in its length near the ladder recess; other larger stones and some with incised figures were arranged on the deflectors of the kivas, where they can readily be inspected.

Many visitors commented on the large number of household implements found here as compared with the paucity of the same at Sun Temple. The explanation of this fact is apparent, for the open-air house was inhabited for a considerable time while Sun Temple never had a population. The scarcity of wooden implements, basketry, and woven fabrics of various kinds is probably due to the exposure of the rooms after they were deserted. Objects of this kind left behind long ago decayed; in some rooms there is evidence on the walls of an extensive conflagration which would have destroyed everything inflammable.

STONE IMPLEMENTS.

A good series of stone hatchets and stone mawls was excavated from the rooms. These are generally grooved and polished, sometimes with sharp edges, although hatchets with rough surfaces and those with blunt edges worn down by hammering are also numerous. A few blades, possibly knives, are very finely chipped. There should also be mentioned well-made arrowheads and half a dozen well-fashioned spear points, but none of these have shafts. Celts called *tcamahia*, peculiar to cliff dwellings, were also found. A stone club unlike any weapon previously reported from the Mesa Verde was found on the surface.

PECKING STONES.

A very large number of implements that were formerly used in dressing the stones of the masonry were naturally excavated both inside the rooms and outside the walls. Some of these had pits on the two opposite faces and were pointed, others were girt by a shallow groove midway in their length. They were made of a much harder stone than that composing the walls of the building and were evidently brought from a distant locality, probably from the Mancos River. One of these made of hematite was more angular than the others. It would appear that these pecking stones were sometimes furnished with a handle.

The many stone mortars and pestles, some of which were much worn, and the numerous metates and manos are instructive. There were also found flat stones on which pigments were ground, and the iron oxides used for paint were not missing. All of these objects are identical with those from the cliff houses and add their quota of evidence to that contributed by the ceramics and architecture, that the pueblos and cliff dwellings of the Mesa Verde were inhabited by people whose cult objects were identical in character.

BONE IMPLEMENTS.

The assortment of bone implements, dirks, needles, bodkins, and the like is instructive. They vary in form, in kind of bone, and other particulars. It is rare to duplicate a perforated needle, one of which was found in kiva A. The skin scraper made of a bear bone is the same as those reported from Cliff Palace. The sections of small bones cut off in a cylindrical form are probably ornaments. Their shape resembles those from Spruce-tree House, suggesting that they were strung on a cord worn about the neck.

ANIMAL FIGURINES.

At least three different forms of stone idols were found, all buried in kivas. In the ventilator of kiva D one of the workmen discovered the head and part of the body of a quadruped made of sandstone, which resembles a bear's head. Another figurine of the same soft stone had head, eyes, and ears fairly well made, but the body elongated and angular, destitute of both legs and tail. The third specimen (fig. 7) was pointed at one end, rounded at the opposite with flat side or base, reminding one of the clay image of the Horned Serpent made at the winter solstice ceremony [1] at Hano, one of the villages on the East Mesa of the Hopi. This striking likeness more than anything else has led me to suspect that it is an idol.

[1] Winter Solstice Ceremony at Hano: Amer. Anthrop., Vol. 1, No. 2, 1899.

CORN FETISHES.

In previous reports on Cliff Palace and Oak-tree House the writer called attention to certain half-oval stones found in kivas that he identified as idols or fetishes. They represent the magnified end of an ear of corn, and resemble specimens made of clay or wood still used in Hopi ceremonies, where they are called kætukwi, corn hills; they are in reality idols of Muyinwu, the god or goddess of germination. When wooden forms are used, symbols of corn of different colors are painted on them, or when made of clay a mosaic composed of kernels of different colored corn is regularly arranged on their surface. They are placed by the Hopi on the floor of the kiva before the altar and from time to time are sprinkled with prayer meal. Two stone specimens were found in the ruin, both of which have the same general form as that from Cliff Palace; one (fig. 6) is covered with a white substance like meal; the other has, near its apex, two small holes of about the diameter of a lead pencil.

POTTERY.

Ceramics as well as architecture presents important evidences of racial culture and the acquisitions from the pueblo, Far View House, are particularly significant. We have extensive collections of pottery from cliff dwellings, but no specimens have been described from the open-air ruins of the Mesa Verde. It is therefore a pleasure to the writer to be able to add to our material the first collection from one of the Mummy Lake mounds[1] that has ever been deposited in the National Museum.

This pottery is practically the same in form, color, and symbolism as that from the cliff dwellings, and supports the evidence of the architecture, that the ruin is prehistoric and comparatively old. It belongs to those archaic generalized types, widely scattered over the Southwest, which antedate specialized and more modern varieties. We find a large proportion of indented, coiled, rough ware, white with black decorations, and a few specimens of imported red with black figures. The figures on the last mentioned are mainly geometric, linear predominating, with curved designs but no life motifs, human or animal. There were comparatively few whole vessels.

ANIMAL REMAINS.

Portions of animal skeletons were found in considerable numbers, especially in room 26, which was evidently a dump place and filled

[1] A considerable amount of "pot hunting" has been done in the cemeteries of this group, in which many specimens of mortuary pottery have been found and later sold to various museums. These are now labeled, "Mancos" or "Mesa Verde," and are useless for a study of the differences in individual cliff houses or comparisons between Mesa Verde pueblos and cliff dwellings.

with débris. Skeletal rejects found here may logically be supposed to reveal the character of the animal food of the natives, but the bones have not yet been fully identified, so that conclusions based on them must be tentative. We are, however, justified in saying, in this preliminary account, that bones of birds, and quadrupeds, such as rabbits, deer, antelope, mountain sheep, and elk, are perhaps the most common. Judging from the number found, it would appear that meat formed a considerable part of their diet, but the indications are that the inhabitants were primarily vegetarians, subsisting mainly on corn, beans, melons, and various wild fruits and herbs, piñon nuts in season, and other products, many of which now grow wild on top of the plateau.

CONCLUSIONS.

We can not say, without more extensive excavations, how much variation may exist in the forms of Mesa Verde pueblos or the arrangement of rooms in them, but all the mounds superficially examined show as a constant feature a marked central depression, apparently indicating a large kiva around which were arranged other and smaller rooms. We find surface indications of the presence of all forms of secular and small circular sacred rooms, from a tower "with rooms arranged around its outer wall" to round kivas embedded among square rooms. The peripheral wall of one or two impart a circular form to the mound; that of others, a rectangular outline.

The theoretical signification of the mounds on the Mesa Verde plateau has not escaped the attention of Baron Nordenskiöld, who arrived at this interesting conclusion which the present writer's excavations prove:

> Much may be said in favor of the opinion that the villages on the mesa and the cliff dwellers are the work of the same people, though no positive proof of this can be given. * * * As far as can be gathered from the heaps of ruins that now mark the site of these villages, the walls are constructed in the same manner as the best built parts of the Cliff Palace or Balcony House, of hewn stone in regular courses. The arrangement of the rooms, the plan of the building, etc., can not be ascertained without extensive excavations, for the execution of which I had no time. The far more advanced stages of decay attained by the ruins may possibly be adduced as evidence of their great age.

The evidence offered by Baron Nordenskiöld to support the theory that the cliff dwellings were abandoned and subsequently repeopled is not as strong as might be desired.

> It is very probable [writes Nordenskiöld, whose honored name will always be associated with the Mesa Verde] that some of the cliff dwellings were inhabited contemporaneously with the villages in the open, and perhaps even later than they. This is suggested by the excellent state of preservation shown by some of the former, for instance, Balcony House. We are forced to conclude that they

were abandoned later than the villages on the mesa. Some features, for example, the superposition of walls constructed with the greatest proficiency on others built in a more primitive fashion, indicate that the cliff dwellings have been inhabited at two different periods. They were first abandoned and had partly fallen into ruins, but were subsequently repeopled, new walls being now erected on the ruins of the old. The best explanation hereof seems to be the following: On the plateaus and in the valleys the Pueblo tribes obtained their widest distribution and their highest development. The numerous villages, at no great distance from each other, were strong enough the defy their hostile neighbors. But afterwards, from causes difficult of enunciation, a period of decay set in, the number and population of the villages gradually decreased, and the inhabitants were again compelled to take refuge in the remote fastnesses. Here the people of the Mesa Verde finally succumbed to their enemies. The memory of their last struggles is preserved by the numerous human bones found in many places strewn among the ruined cliff dwellings. These human remains occur in situations where it is impossible to assume that they have been interred.

The supposition that the cliff dwellers were exterminated by their enemies in their eyrie homes appears to the writer improbable; nor is there ample proof that such a catastrophe as that mentioned in the closing lines of the above quotation took place while they inhabited the plateau. The "numerous human bones found in many places strewn among the ruined cliff dwellings" admit of another explanation. The disjointed skeletons may have been left there by "pot hunters" who tore them out of their graves and sacrilegiously strewed them over the floors of the rooms. The writer does not believe all the aborigines of the plateau were destroyed in or near their cliff dwellings or on the plateau. He holds the opinion that they migrated in groups large or small to the plains. The Utes, their enemies, have a tradition that they fought and killed many of the ancients inhabiting the valleys at Battle Rock, near the Sleeping Ute Mountain at the entrance to the McElmo Canyon.

In a comparison of the pueblo above described with cliff dwellings protected by the natural roof of a cave (pl. 12) the amount of denudation of walls should have little weight in determining chronology, for the wear resulting from rains beating on the walls is reduced to a minimum in the latter case, while in the former it is very great. The walls of pueblos built centuries later often suffer much more erosion than cliff houses in the same length of time.

The relative excellence of the masonry is also not a safe chronological guide, for it degenerates as well as improves with successive generations of workmen. Poor masonry generally but not always antedates good masonry. The houses in Hopi villages, still inhabited, are not as well made as those of buildings now in ruins, in which they say their ancestors lived. If legends are reliable the skill of the Hopi masons has deteriorated; they have lost the ability they once exercised. Thus it by no means always follows that the walls of a well-made pueblo ruin are necessarily more modern than one with

ruder walls. These considerations throw doubt on the theory that the character of masonry or the amount of erosion are good criteria by which to determine the relative age of pueblo buildings and cliff dwellings.

The second question, "How old are the cliff dwellings?" is impossible to answer, but we know that cliff dwellings were not inhabited in historic times. Comrades of Coronado, in 1540, left no records of cliff dwellings in New Mexico, but Castañeda mentioned many inhabited pueblos, which is an argument in support of the theory that the latter was a phase of architecture subsequent to the cliff house. No light is thrown by the writer's excavations on relative chronology, for no one can tell the age of either type of ruins in the Mesa Verde; nor is it possible to say that the buildings at Mesa Verde are older or younger than some of the Chaco, Animas, McElmo, or Montezuma Valley ruins, although the walls of the pueblos on top of Mesa Verde are as a rule worn down more by the elements than are those in the valley and therefore of a greater antiquity. The annual erosion of an artificially exposed wall on Mesa Verde is probably about the same in extent as in case of walls in the valleys mentioned. Since, as a rule, the walls of the latter stand higher out of their mounds, the logical conclusion would be that the higher walls are more modern than the lower, but other facts must also be considered before this can be stated as a law.

In a general way we can explain the supposed later construction of pueblos in the San Juan or its tributaries by the theory that their ancestors lived on the Mesa Verde, and that they left their ancient homes and settled in the Mancos or Montezuma Valley, whence they later spread down the river to distant points, as far as evidences of their culture can now be traced. This would seem a more natural conclusion, considering all the facts, than the theory, formerly advocated by the writer, that pueblos were developed in the river valleys before the ancients went on the mesa.

The likeness of the pueblo excavated to the open-air community houses along the San Juan and its tributaries is close enough to indicate identity of culture. As long as we were unacquainted with the essential features of the pueblos on the plateau we were unable to make close comparisons with adjacent cliff houses. The resemblances of community houses 100 miles distant from the cliff dwellings were known to be close, but the pueblo excavated furnishes us with a connecting link in our chain of similarities near at hand and on that account is of preeminent importance in a cultural comparison.

The resemblance between the pueblo on Mesa Verde and those of the McElmo and Montezuma Canyons, and the similarities to

buildings in the La Plata and Animas Valleys have long ago been recognized as a likeness of culture, but whether the latter are older or more modern than the Mesa Verde pueblos is still one of the many unsolved problems awaiting additional research.

If the plateau building excavated owes its form to a survival of that developed in caves, it is therefore evidently of later construction and this would indicate that the pueblos of the San Juan and its tributaries are also of later date than the cliff dwellings, or, in other words, that architectural characteristics of Mesa Verde pueblos were originally formed in cliffs and the congested forms there produced were later transmitted to the valleys.

The Mesa Verde pueblo presents no certain evidence that its type of building is more modern than the cliff-house phase, but if the above conclusion be correct a natural corollary would be that identical open-air community houses in the San Juan and its tributaries were settled subsequent to the cliff dwellings of which the Mummy Lake settlement is a survival. Although we have no way of telling how old the Mesa Verde cliff dwellers or plateau habitations are in terms of the Christian calendar, the writer, unlike some other archeologists considers them comparatively modern; which does not mean, however, that man has not lived on the mesa in some degree of culture for a long time previously, but only that he was not a cliff dweller or a Pueblo Indian several thousand years ago. We have some evidence of the existence of a pit-house culture, with certain kinship to the puebloan, but the age of this no man knows with any more precision than he does the cause which forced man originally to make any kind of a home in the secluded fastnesses of the Mesa Verde.

An answer to the last and most difficult of all questions, "What became of the inhabitants?" is implied in the preceding lines. The writer has held that the cliff dweller constructed a pueblo after he abandoned the caves, and believes man later moved to the valleys, where his culture still survives. This culture is most apparent among the least modified living pueblos, as the Hopi. Of course it is not claimed that individual clans migrated directly to the Hopi country from Mesa Verde, but their culture traveled down the San Juan River Valley and ultimately was brought to Hopi land.

It is certain that some of the Hopi clans lived in cliffs. The Snake people have definite legends that they once inhabited the great cliff houses of the Navaho National Monument Betatakin and Kitsiel. These Hopi legends, and similar stories found among other pueblos, are supported by many facts besides architectural and ceramic resemblances. Ownership in eagle nests near cliff ruins are claimed through inheritance by the Snake clans, because they were ancestral

property. Water from the cliff dwellers' spring is still sought and used in some ceremonies of the Hopi for the same reason.[1]

These and many other facts support the legends that some of the Hopi clans are descended from cliff-dwelling clans or those formerly living in pueblos near cliff dwellings.[2] Not the least important fact supporting this statement is the identity in artifacts among the two peoples.

As the only other building situated under the open sky on the plateau is Sun Temple, it is natural to consider whether the newly excavated ruin throws any light on the purpose of this mysterious structure.

In general form there is no likeness between the two buildings, although certain details of masonry show the handiwork of a people in the same stage of culture. The Mummy Lake pueblo lacks the unity and dignity of the religious building and presents evidences of having been repeatedly patched, as if constructed at intervals by different masons, often unskilled workmen. Its walls have been shattered and repaired. Buttresses were constructed by the aborigines to prop it up in places before they deserted it, and, as a rule, the masonry is poorer. In Sun Temple we find two kivas in an open court separated by passageways from bounding walls; in the new ruin domiciliary and ceremonial rooms are massed or crowded together, the court being situated not within the main structure but extramural, surrounded by a wall on the south side.

There is a certain likeness in what has been designated the kiva of the annex of Sun Temple to the small kivas of the pueblo, but the arrangement and form of rooms about them are different. The ventilation of the Sun Temple kivas was accomplished in a different way. The secular rooms are larger, doorways higher and broader in the ruin excavated at Mummy Lake than in Sun Temple.

The writer desired to find decisive evidences in his field work at Mummy Lake supporting or denying that the name, Sun Temple, was well given to the mysterious ruin opposite Cliff Palace. In that hope he was disappointed, but not wholly. The work above briefly outlined confirms his belief that Sun Temple and Far View House of the Mummy Lake group of buildings were constructed by an

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[1] On a visit to Betatakin a large cliff house of the Navaho Monument, in northern Arizona, a few years ago, a Hopi courier, who was on a pilgrimage there to obtain water from an ancestral spring, told the writer, in sight of the ruin, that the ancestors of the Snake people once lived there.

If the ancestors of the largest clan in Walpi once inhabited the cliff houses of the Navaho Monument, and if the cliff dwellers of the San Juan had a culture identical with them, can it reasonably be doubted that cliff dwellers transmitted their blood and culture to pueblos, where they still survive?

[2] A discussion of all the causes of the desertion of the Mesa Verde villages, cliff dwellings or pueblos would take me too far afield for this article. Little can be added to the able remarks by Dr. Prudden in his analysis of the influence of climatic changes. See loc. cit.

aboriginal people in comparatively the same cultural stage as the cliff dwellers.

Far View House is a pure type of pueblo building, limited to prehistoric times, its essential differences from the mixed or historic type, characteristic of modern pueblos, being its compact form and circular kivas embedded in surrounding house walls.

It is desirable, now that the general features of one of these have been excavated, to extend the work to other neighboring mounds of the group. The writer hopes some day to see all these mounds exca-

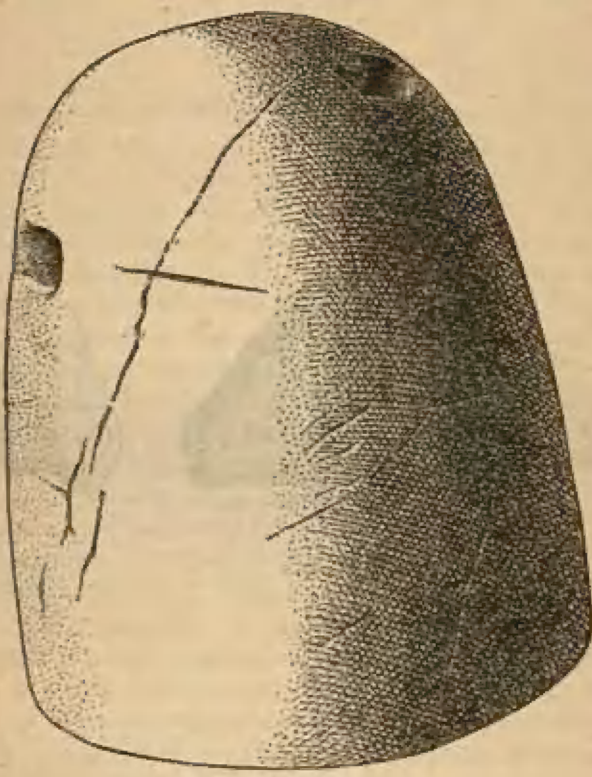


Fig. 6.—Corn fetish.

vated and repaired. The sight of a dozen large, well-constructed pueblos in an area half a mile long by a quarter of a mile wide would be as instructive as exceptional. The excavation and repair of this cluster of mounds would be a worthy task for any institution to undertake, fraught as it is with so many problems of archeological interest, but it would require an enthusiastic devotion to scientific research supported by a large sum of money and many months of arduous toil by skilled workmen.

FIG. 7.—Stone idol.

THE ART OF THE GREAT EARTHWORK BUILDERS OF OHIO.[1]

By Charles C. Willoughby.

[With 13 plates.]

One of our most interesting as well as least understood archeological culture groups is that which attained its greatest development in southern Ohio, and whose outposts extended into some of the neighboring States. This group of people had attained a high degree of native culture and had become wealthy and powerful according to native standards. They had mastered certain simple geometrical problems, which were apparently unknown to their neighbors; they had learned the principle of the lathe, and made the first cutting tools of iron so far known in America. It seems that nearly all of the greater earthworks of southern Ohio were built by them, but some of the smaller mounds, inclosures, and burial places should doubtless be attributed to other tribes.

The great earthworks under consideration are unquestionably prehistoric and apparently antedate the occupancy of this region by any known tribe. They consist mainly of round, square, and octagonal inclosures, protected ways, burial mounds, and a few domiciliary and effigy mounds. No object of European origin has been found with any of the original burials in these mounds. Intrusive burials of the later Indians are, of course, occasionally encountered, but these must not be confused with original interments. Most of the artifacts, illustrated in this paper, were taken from mounds containing skeletons and clay altars or places of sacrifice. The explorations were conducted under the general direction of the late Prof. F. W. Putnam, by Dr. Metz, Mr. Moorehead, and others. The specimens from the Turner and Liberty groups are in the Peabody Museum of Harvard University, and those from the Hopewell group are in the Field Museum at Chicago.

The skeletons and altars for the greater part were found near the base line of the mounds. The altars are usually heaps of clay, raised 1 foot or more in the center and have sides sloping out-

[1] Reprinted by permission from Holmes's Anniversary Volume, pp. 469–480, Washington, 1916.

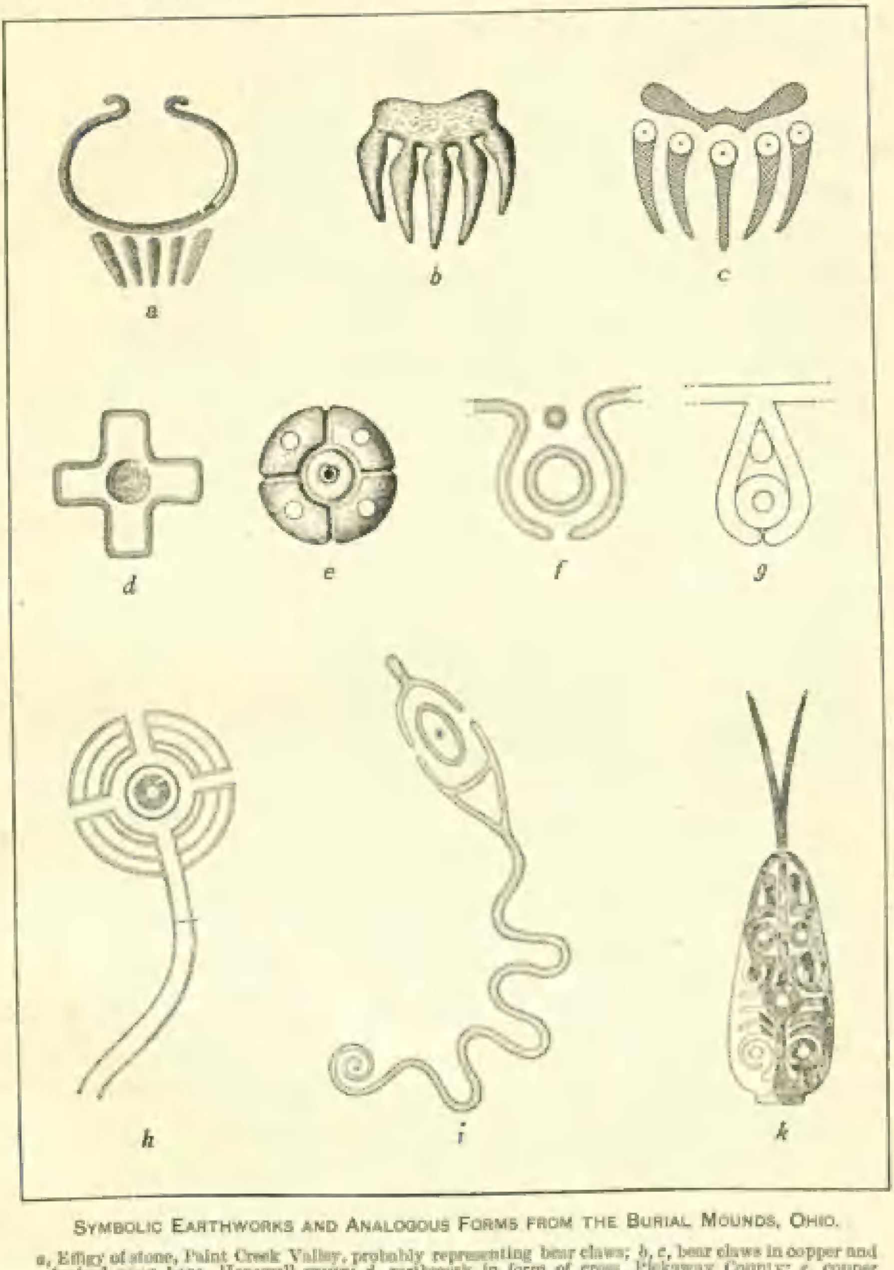
ward and a depression a few inches deep in the top, which usually shows signs of extreme heat. These altars are of various sizes, but usually the cavity or depression is about 3 feet in diameter. In the larger mounds, which have been systematically explored, notably those of the Porter, Hopewell, Turner, and Liberty groups a considerable number of skeletons were found in the same mounds with the altars. The number of altars occurring in a single mound ranged from one to four. It is from the altars that many of the objects described in this paper were taken. Other specimens illustrated were found with skeletons or in deposits near them.

SYMBOLIC EARTHWORKS

Among the most interesting of the earthworks, when regarded independently of the artifacts they contain, are the effigy mounds, which appear to be related symbolically to certain objects recovered from the tumuli. A brief notice of some of them may be of interest.

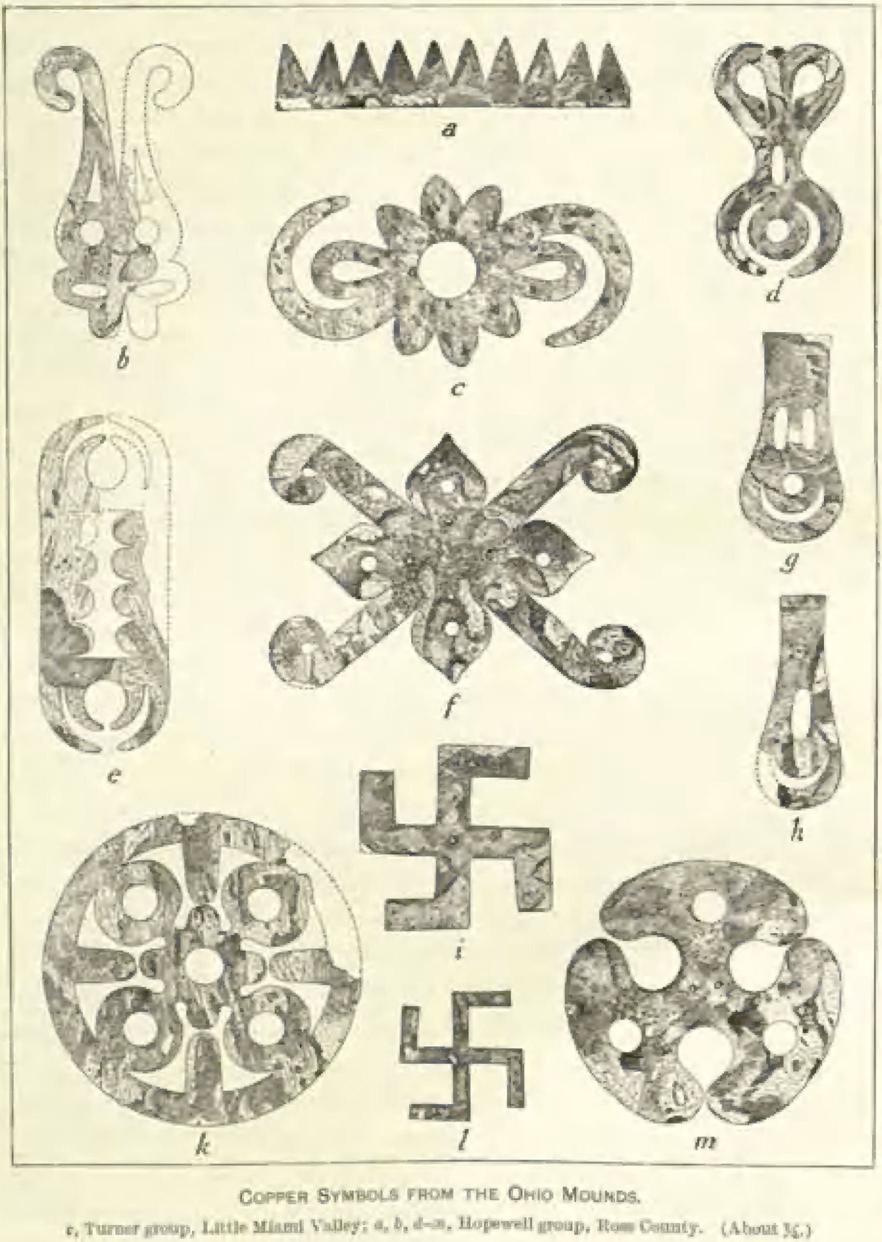
The Serpent Mound of Adams County is the best known of the few earthworks of this class. The illustration of this work shown on plate 1, *i*, is reproduced from Prof. Holmes's drawing, made in 1886, and undoubtedly represents the effigy much as it appeared to its builders. MacLean's plan, made from careful surveys in 1885, agrees with the above very closely, the principal difference being in the broadening of the extreme projection in front of the oval and the adding of two small spurs thereto. Squier and Davis's drawing is incorrect in several respects, and seems to be more like a sketch-plan made without surveying instrument than the accurate survey claimed by them. In the Peabody Museum of Harvard University there is an unfinished plan from a survey made by Thomas P. Gore, of Hillsboro, Ohio, in 1878, which corresponds to those of MacLean and Holmes with the exception of the wishbone-shaped section in front of the oval which is not indicated. In this plan the embankments upon either side of the rear half of the oval which connect with that of the triangular inclosure appear as shown by both MacLean and Holmes. Portions of these, and the wishbone-shaped embankment inclosing the front of the oval, were much less conspicuous than the oval and the main portion of the serpent. These were not considered by Prof. Putnam as parts of the effigy at the time of its restoration. Before entering into details regarding the peculiar features of this earthwork, I desire to call attention to the serpent head wrought from copper shown in plate 1, *k*, which was found with many other copper objects in the great mound of the Hopewell group.

As is well known to anthropologists, the serpent occupied a prominent place in the religious life of many tribes north of Mexico, as well as in Mexico and Central America, and it appears in combination with the cosmic symbol, or some of its parts, in various sections.



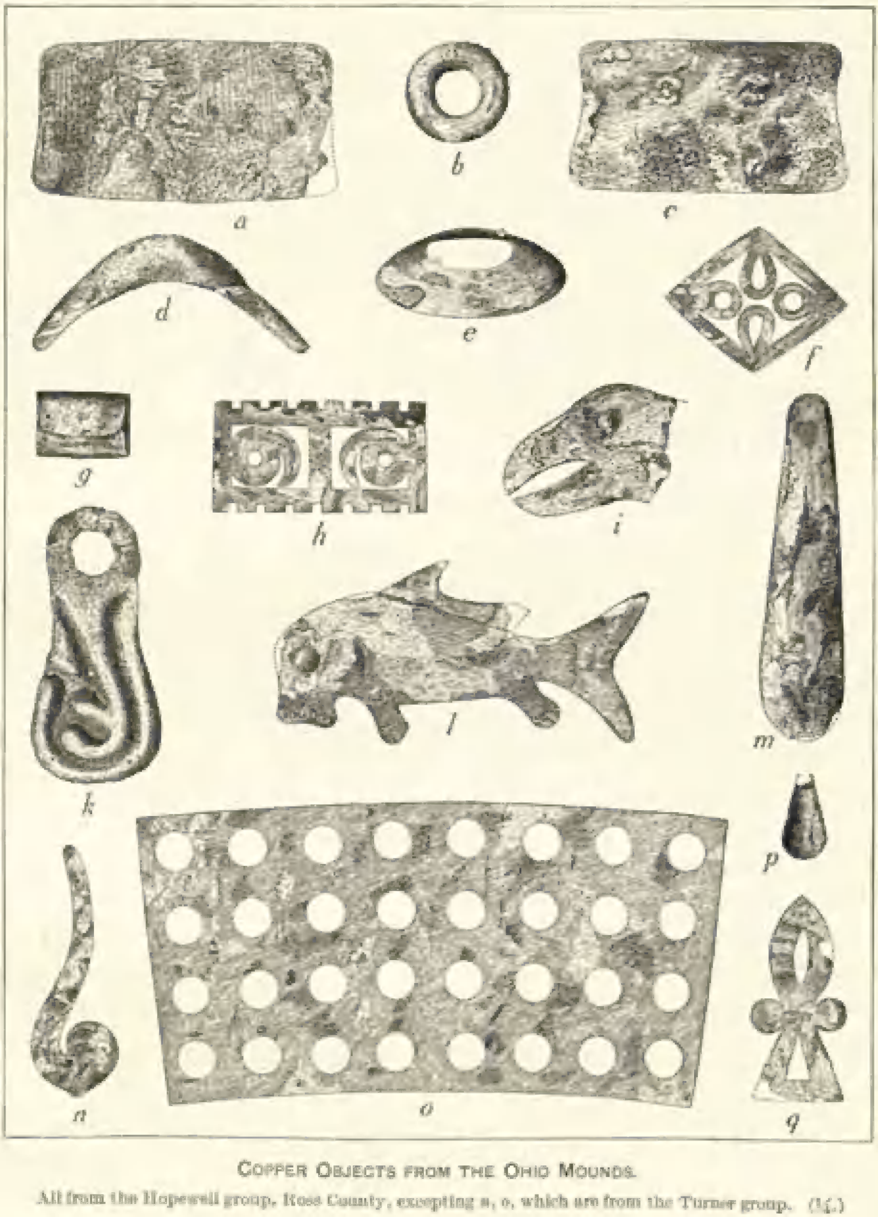
SYMBOLIC EARTHWORKS AND ANALOGOUS FORMS FROM THE BURIAL MOUNDS, OHIO.

a, Effigy of stone, Paint Creek Valley, probably representing bear claws; *b*, *c*, bear claws in copper and incised upon bone, Hopewell group; *d*, earthwork in form of cross, Pickaway County; *e*, copper ear ornament with cosmic symbol, Hopewell group; *f*, gateway to great inclosure near Hamilton, Butler County; *g*, same design incised upon bone, Hopewell group; *h*, portion of great serpentlike earthwork near Portsmouth; *i*, serpent mound, Adams County; *k*, cosmic symbol in form of serpent head, in copper, Hopewell group. (About 1/6.)



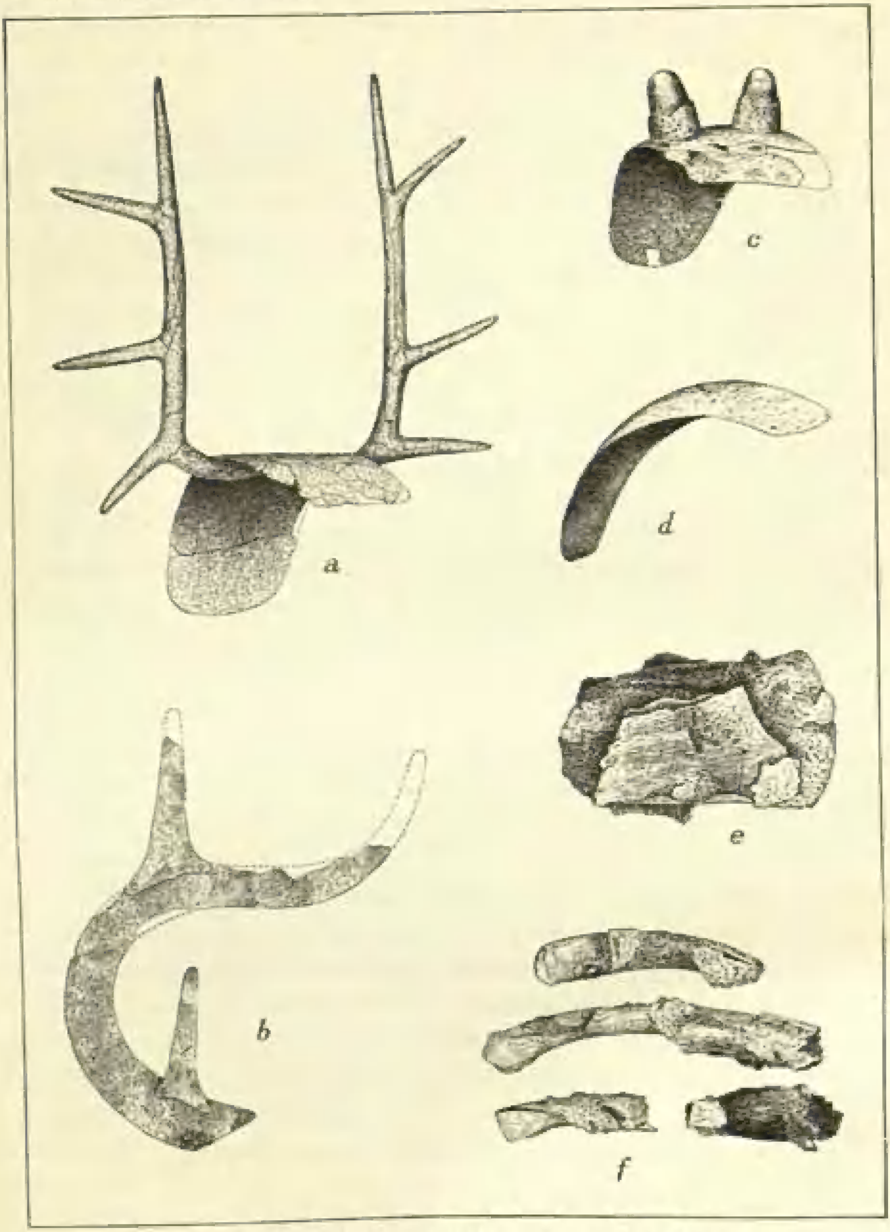
COPPER SYMBOLS FROM THE OHIO MOUNDS.

c, Turner group, Little Miami Valley; a, b, d–m, Hopewell group, Ross County. (About ½.)



COPPER OBJECTS FROM THE OHIO MOUNDS.

All from the Hopewell group, Ross County, excepting a, o, which are from the Turner group. (½.)



METAL HEAD ORNAMENTS AND TOOLS FROM THE OHIO MOUNDS.

a, Head ornament of copper and wood, representing full-grown deer antlers; *b*, deer antler cut from copper; *c*, head ornament with sprouting antlers of copper and wood; *d*, copper headplate; *e*, meteoric iron blade; *f*, meteoric iron chisels, two of which have portions of antler handles still adhering. (*a–d*, 1/2; *e–f*, 1/2.)

The cosmic symbol in its complete form represents the world as known to the Indians and usually consists of a circle or concentric circles inclosing a cross and a central disk or circle. This is said to represent the sun, the four directions or four winds, the horizon, and also the earth, air, and water; sometimes a dot or a circle appears in the center of each of the four world-quarters. The swastika is undoubtedly derived from this sign. The serpent, which may be regarded as the god of wind, rain, and water, and the antithesis of the sun, often appears in combination with the cosmic symbol or parts thereof. The shell serpent gorgets of Tennessee are well-known examples. In these, the serpent is coiled in the center of the disk and the four arms of the cross connect it with the outer circle as in figure 1. A rarer form in shell of a serpent head with a circle and cross also from Tennessee, is also shown in the accompanying drawing.[1]

Returning to the copper symbol (pl. 1, *k*), it is at once apparent that we have a serpent head in combination with the cosmic sign. The outline of the latter instead of being circular conforms to and forms a part of the outline of the head, and the arms of the cross which radiate from the central sun circle are unequal. In the serpent portion of the symbol we have the forked tongue (which was not attached to the head when found, but evidently belongs with it), the nostrils, eyes, two U-shaped designs back of the eyes, and on each side near the base of the head an eyelike design with two curved toothlike appendages, analogous to those on the mica serpent shown on plate 9, *m*. These probably represent the four horns which appear on most serpent designs north of Mexico, and replace the plumes of the serpent deity of Mexico and Central America.

Fig. 1.—Combined cosmic and serpent symbols.

With the above interpretation in mind, we will turn to the drawing of the serpent mound with a clearer understanding of this remarkable effigy, which probably represents a serpent in its entirety, combined with the cosmic symbol.

The outline of the serpent head is marked by the interrupted oval, from the front of which projects the tongue. It is interesting to note that in MacLean's drawing there are two narrow diverging projections from the sides of this appendage near its free end, which he calls the forelegs of the "frog." If these pointed projections really existed, they undoubtedly represented the fork of the tongue. The inner oval inclosing the altar of stones where fires symbolizing the sun were

[1] The Archeologist, vol. 2, p. 12.

kindled is doubtless similar to one of the inner circles which occur in many of the symbols of this class. This, together with the outer interrupted oval, was compressed to conform to the outlines of the reptile's head. The opposite openings in the outer oval may represent two arms of the cross. They seem to be analogous to similar openings shown in *h* of the same plate. It is not improbable that these may have been at one time a cross within the oval.

I am well aware that the above interpretation of the serpent effigy is at variance with all others, but it is much more in keeping with what we know of the symbolism of these Indians than that of Squier and Davis, who saw in it a serpent with open jaws swallowing or ejecting an oval figure, or of MacLean, who thought it represented a frog ejecting an egg into the open jaws of the snake.

A very remarkable earthwork which seems to be of like nature to the one described above occurs on both banks of the Ohio River near Portsmouth. It is shown on plates 27 and 28 of Squier and Davis. A portion of this is illustrated on our plate 1, *h*. It consists of a truncated central mound surrounded by a ditch and having a graded way to the top. This is inclosed by concentric circles interrupted by passageways in the form of a cross. This great cosmic symbol is 1,300 feet in diameter and is connected with a group of works 3½ miles distant by serpentlike parallel lines of earthworks. This gigantic conventionalized figure probably embodies ideas similar to those of the serpent mound.

In Paint Creek Valley, near Bournville, is an effigy of stones[1] which is reproduced on plate 1, *a*. It is about 250 feet in diameter and doubtless represents the foot and claws of the bear. Analogous designs are shown in *b* and *c*. The former is cut from copper and the latter forms a part of the design incised upon the human femur illustrated in *i*, *l*, plate 6.

The earthwork in the form of a cross with the central sun symbol[2] shown in *d*, occupies a narrow spur of land in Pickaway County. This undoubtedly embodies a meaning similar to that of the cross and central circle represented in *e*, *h*, and *k*. The gateway to the great inclosure near Hamilton, Butler County,[3] is represented in *f*. This is probably also symbolic, as we have a like design upon the bone shown in *g*, and plate 6, *i* and *l*.

ARTIFACTS OF METAL.

In common with other American tribes, the builders of the great earthworks of Ohio had become proficient in working native copper. This metal seems to have been highly prized in this region and was made into a great variety of ornamental or symbolic forms. Its

[1] Squier and Davis, plates 3 and 30. [2] Ibid., plate 26. [3] Ibid., plate 8.

practical use seems to have been limited principally to ax and adz-blades, which occur in considerable numbers with burials or as parts of sacrifical deposits. Indeed, it is not improbable that these copper blades were esteemed as much for their intrinsic worth as for their efficiency as tools. A large number of copper blades were found near two skeletons in the great mound of the Hopewell group, the largest of which weighed 38 pounds.

The greater number of the artifacts of copper that have been recovered are of an ornamental or symbolic character. Most of the copper from which they were made undoubtedly came from the Lake Superior region, although some may have been obtained from erratic masses carried southward by the ice sheets in glacial times. The purest and most ductile pieces were used in the formation of thin sheets for covering various ornaments, or for cutting into symbolic forms; and the less malleable masses were worked into objects which did not require as much hammering. Some of the nuggets taken from the altars in an unworked or slightly worked state contained impurities which rendered their further working impossible or unprofitable. Experiments conducted by the present writer[1] show that alternate hammering and annealing are essential to the successful working of native copper into thin sheets, and it is probable that the aid of fire was sought by most Indians in working this metal into any form that required much hammering.

The specimens shown on plates 2–5 were taken from burial deposits and altars in the great mound of the Hopewell group (Clark's Works), Ross County, from the mounds of the Turner group, Little Miami Valley; and from the Liberty group of Ross County, most of them coming from the first locality. Figures *i* and *l* represent the straight-armed swastika. As will be seen by turning to *f*, plate 10, it is not improbable that these objects were worn at the back of the head.

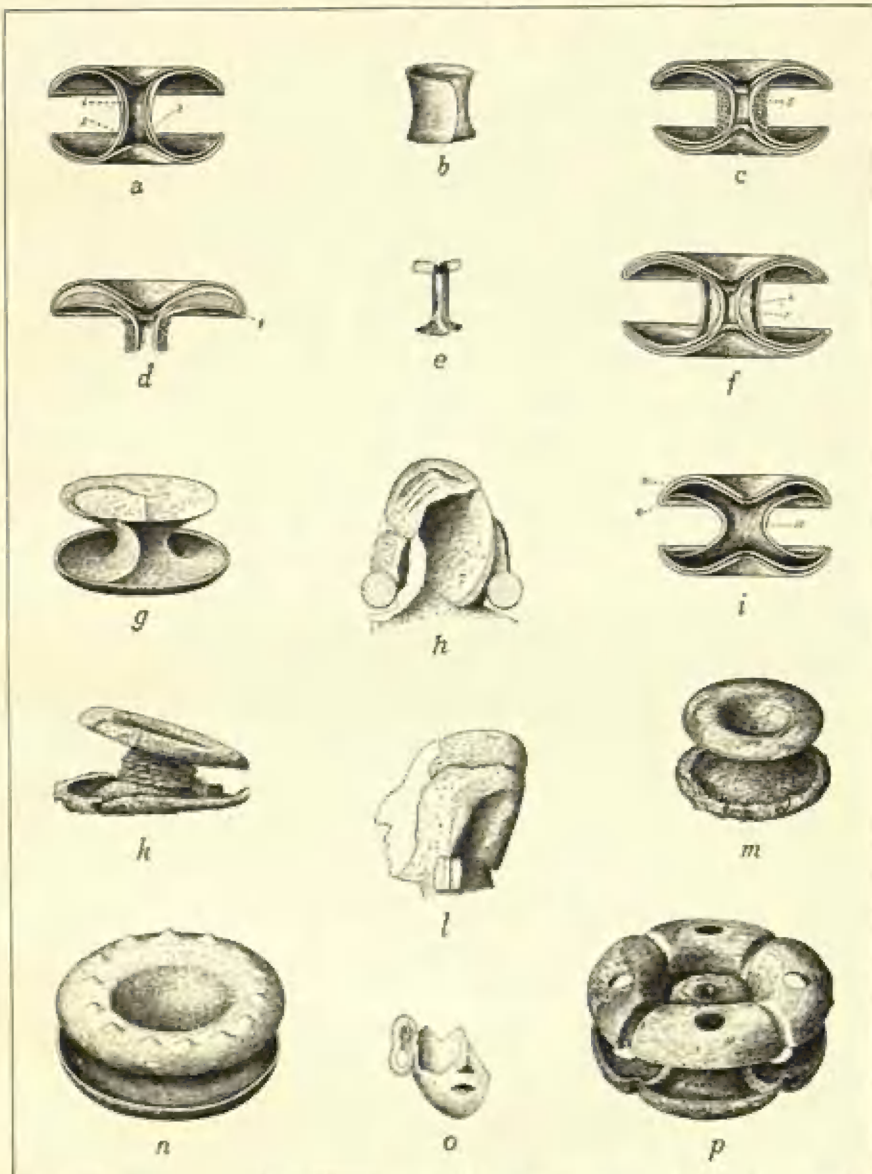
The design shown in *k* is undoubtedly a cosmic symbol, and the analogy of its more prominent features to those of the serpent head, plate 1, *k*, seems apparent. The designs *d*, *g*, and *h* are undoubtedly derived from the human face, and they show a marked sense of humor on the part of the artisan who made them. On plate 3, *a* and *c*, are represented two gorget-like plates such as are usually found with skeletons. One of these shows the remains of a piece of twined woven textile which had been preserved by contact with the copper. *d* and *g* are drawings of a crescent-shaped gorget and what is probably a bracelet. These were found with a skeleton. And on the same plate, *h*, is a conventionalized representation of the double serpent head which appears on the Cincinnati Tablet. What is

[1] American Anthropologist, N. S., Vol. 5, p. 55.

apparently a frontlet is illustrated in *o*. Two of these were taken from one of the altars of the Turner group. So far as we may judge from specimens thus far recovered, the great earthwork builders of this region had not attained a proficiency in embossed work which equaled that of some other sections. Overlaying, however, was followed in making a considerable variety of objects. One of the most elaborate examples of this work is shown in two of the head dresses on plate 4. The antlers of the largest of these are made from carefully selected branches of wood, covered with thin sheets of copper. The cores of the sprouting antlers on the second head dress (*c*) are also of wood, very neatly covered with thin sheets of the same metal. Some excellent examples in overlaying are shown in the ear ornaments, bracelets, beads, and button-like objects where the foundation is of clay, wood, or copper, and the overlaying is of thin sheets of silver, meteoric iron, or selected copper. Bracelets of metal occur frequently with burials and are sometimes found upon altars, and while the form varies somewhat, they are usually of the simplest construction. Some of these are of copper, very neatly overlaid with thin silver.

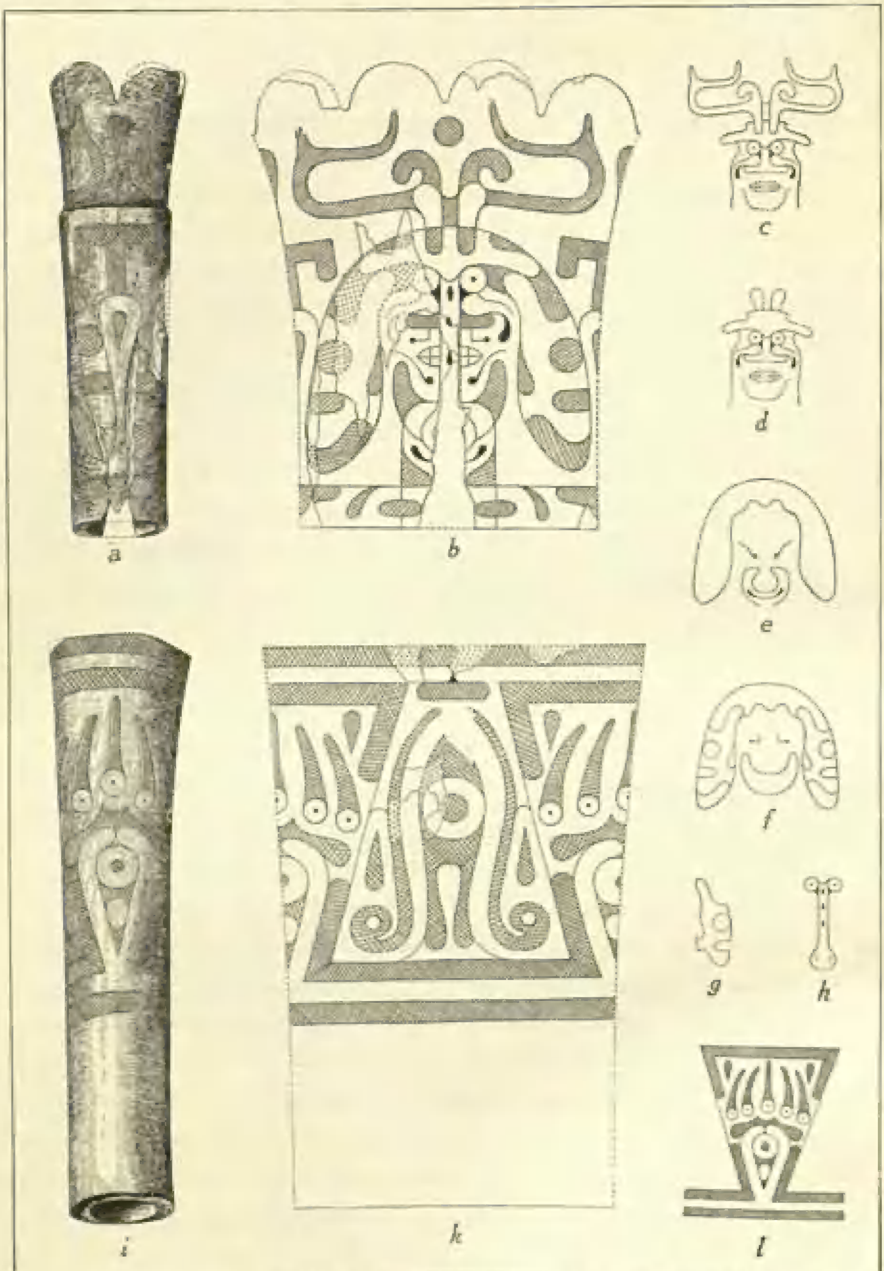
One of the most common personal ornaments of metal is the ear plug, illustrations of which appear on plate 5. These are often found with skeletons and also occur in considerable numbers on the altars. A part of the head of a terra-cotta effigy from an altar of the Turner group is shown in *h*, *l*, which illustrates the manner of wearing these ornaments. Another fragment showing the perforation in the lobe of the ear for the insertion of the ornament is illustrated in *o*. Unusually fine specimens of these ornaments are shown in *n* and *p*. A pair of each of these was found with the extensive copper deposit in the great mound of the Hopewell group.

Various methods of constructing these objects are shown in *a–g*, *i*. A hollow rivet, made by rolling together a strip of copper, usually connects the inner plates of the two disks. One of these is shown in *e*. Their relative positions are illustrated in the cross sections *a*, *c*, *d*, *f*. Another less common method of joining the disks is illustrated in *g* and *i*. Here the ends of the pulley-shaped piece of copper are much expanded, and to these the disks are secured by turning under the edge of the outer plate. In *g* the upper disk has been removed to show the construction. In most of the specimens each of the two disks which are joined by the rivet is made up of two or three plates, the outer of which is of carefully wrought copper, silver, or meteoric iron. Sometimes, to assist in keeping the plates in their proper positions, the space between them is filled with clay (*d* 4), which upon drying adds much to the firmness of the ornament. Sometimes the rivet is reinforced by hammering a piece of metal



COPPER EAR PLUGS FROM THE HOPEWELL GROUP, OHIO.

a, *c*, *d*, *f*, *i*, Cross-sections of ear-plugs, showing methods of construction; *b*, *e*, *g*, pieces of copper prepared for connecting the disks; *k*, *m*, *n*, *p*, finished ear plugs. (About 2/3.) *h*, *l*, two views of portion of head of terra-cotta figurine, showing ear plugs in position; *o*, fragment of head of terra-cotta figurine with lobe of ear perforated for insertion of ear plug, Turner group. (About 1/1.)



ENGRAVINGS FROM THE HOPEWELL GROUP, OHIO.

a, *i*, Engravings on portions of human femora ($\frac{1}{2}$); *b*, complete design on *a*; *c*–*h*, elements forming the composite design of *b*, somewhat reduced; *k*, complete design on *i*; *l*, portion of the design on *i*, reduced. Found with skeletons.

around it as illustrated in *f* 6, or by the use of an outer band *b*, applied as *f* 7, or the rivet may be wound with vegetal fiber or cord as in *k*, *d*, and *c* 5.

OTHER METALS.

The occurrence of meteoric iron in most of the mound groups that have been systematically explored, in the form of nuggets or worked into various objects, shows that its malleability was generally understood by the people of this region. It was worked into headplates, breastplates, beads, coverings for ear plugs, adz blades, chisels, and drills. Plate 4 *e* shows a meteoric iron blade, and several chisels of this metal with portions of antler handles still adhering to two of them are illustrated in *f*.

Native silver sometimes occurs in considerable masses in the mounds. There are two nuggets in the Peabody Museum of Harvard University, the combined weight of which is 13¾ pounds. These were taken from a mound at Grand Rapids, a northern outpost of the Ohio culture group. Silver seems to have been used principally for overlaying copper and wooden objects, such as buttons, ear plugs, and bracelets. Many beads were also made of silver, some of them being quite massive.

Gold was very rare indeed in the mounds. There are one or two references by early writers to finding of gold objects, but the only authentic specimens known to the writer are several small sheets hammered from small nuggets, which were taken from an altar of the Turner group and are now in the Peabody Museum at Cambridge.

ENGRAVINGS UPON BONE.

The decorated human femora illustrated in plate 6, *a* and *i*, were found with skeletons in the great mound of the Hopewell group, and the designs engraved upon them are shown developed in *b* and *k*. The different parts making up the composite human head and its appendages in *b* are illustrated, somewhat reduced, in *c*–*h*. In *c* and *d* we have human heads wearing headplates supporting antlers similar to those shown on plate 4, *b* and *c*. What appears to be the beak of the spoonbill is represented in *h*.

Two more of these remarkable engravings are illustrated on plate 7. The upper one, *a*, was taken from an altar of the Turner group in a fragmentary state. The developed design appears in *b* and *c*, and the more prominent features composing the design are shown somewhat reduced in *d*, *e*, *f*. The conventionalized head of what may be the bison appears only when the design *c* is reversed.

The specimen illustrated in *g* was found in 1801 in a mound at Cincinnati. The developed design, *h* and *i*, are from drawings by

Dr. G. B. Gordon, and are described by him in volume 2 of the Transactions of the Department of Archæology of the University of Pennsylvania. It is a highly conventionalized drawing of one of the carnivora.

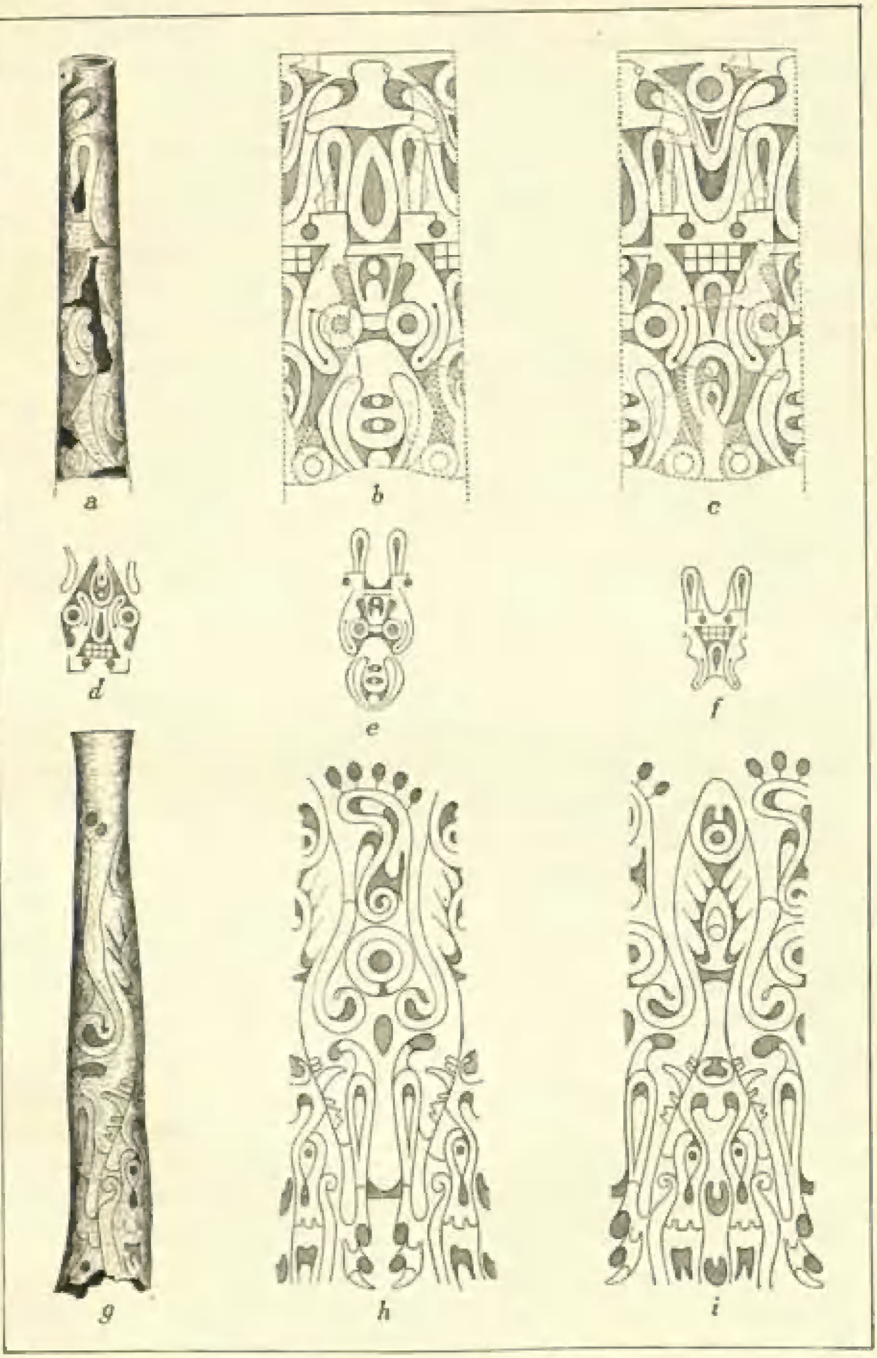
The remarkable designs illustrated on plate 8, *g* and *h*, are incised upon disks cut from the parietal bones of a human skull. They are from an altar of the Turner group. The designs are alike, excepting that they are reversed. Each consists of three highly conventionalized bird forms joined together. The central bird with ears and with large legs terminating in four claws probably represents an owl. The other two are less easily identified.

The spatula-like implement shown in *b*, made from the rib of a large mammal, is also from the Turner group. The bird incised upon the handle is one of the most artistic Indian drawings thus far known. The lines were originally filled with red pigment.

Those shown in *c*, *d*, *e*, *f* are from the Hopewell group. *c* is carved upon the thin bone of a large bird and represents the ocelot; the markings upon the body are true to nature, and although somewhat conventionalized, they occupy their proper position.

MICA OBJECTS.

Mica was highly valued and was obtained in considerable quantities by the earthwork builders, probably from the Appalachian region. The crystals or plates are often of large size, and are frequently found with skeletons or as sacrificial deposits in the mounds. The thin sheets into which these plates are easily divided were sometimes cut into ornaments or symbolic figures, such as are shown on plate 9. These were taken from altars of the Hopewell and Turner groups with many fragments of similar objects cut from this mineral. The edges are as smooth and even as though cut with a sharp steel implement. Experiments, however, show that small flaked knives of flint will do the work equally well. The perforated disks, *a* and *c*, were cut with some kind of instrument for describing accurate circles. Fragments of large symbolic designs of a nature similar to those cut from copper are shown in *e–h*. The general method of laying out a design is illustrated in *i*. This was evidently done in freehand with a sharp flint. Figures *l* and *o* are in the form of stone knives or projectile points. Figure *l* was lying in contact with an obsidian implement of like form and has incised upon its surface the outline of what is apparently a barbed spear point. That these people were familiar with the atlatl or spear thrower is evident from the design shown in *n*. An interesting delineation of the horned serpent is shown in *m*. It should be noted that the disk from the center of which the long horn projects has two short arms which lie



ENGRAVINGS FROM THE OHIO MOUNDS.

a, Engraving upon portion of a human ulna, Turner group of mounds ([illegible]); *b*, *c*, complete design upon *a*, two developments; *d*, principal design shown where *c* is reversed; *e*, principal design shown in *b*; *f*, principal design shown in *c*; *g*, engraving upon bone found in mound at Cincinnati in 1801 (after G. B. Gordon); *h*, *i*, complete design upon *g*, two developments.

ENGRAVINGS FROM THE OHIO MOUNDS.

a, Fragment of thin shell engraved upon both sides; *b*, fragmentary spatulalike object made from rib bone; *c*, figure of ocelot upon bird bone; d, engraved antler object; *e*, developed design upon *f*; *f*, engraving upon bone; *g*, *h*, engraved disks cut from the parietal bones of the human skull. (About ½.) *b*, *g*, *h*, Turner group; all others, Hopewell group.

against the horn for a part of its distance. If we eliminate the long horn we have remaining a disk with two arms and a central perforation, a form analogous to those occupying similar positions upon either side of the serpent head shown in *k*, plate 1. The grotesque human head, *k*, is another good illustration of the humor of these Indians. The excellent representation of the upper portion of a bear is illustrated in *b*. This is one of several taken from an altar of the Turner group. Portions of these effigies were carefully painted in red, brown, and pink pigment. Several birdlike objects which had originally been painted were taken from this altar. One of these is shown in *d*.

TOBACCO PIPES.

The remarkable collection of tobacco pipes obtained by Squier and Davis from the altar of one of the tumuli of "Mound City" is too well known to archeologists to be considered here. Mr. W. C. Mills, of the Ohio Archæological and Historical Society, made a similar find in 1915.[1]

One of the most elaborate pipes so far recovered is illustrated on plate 10, *a*, *b*. This was taken from one of the altars of the Hopewell group and represents the spoonbill resting on the back of a fish. The cavity for the tobacco is in the body of the bird and the perforation for the passage of smoke extends through the body of the fish, the outer opening being its mouth. This appears to be made from a kind of claystone and is colored black by the confined smoke of the altar fires. A front view of the bird's head and beak is shown in *k*. The incised lines extending from the nostrils to the tip of the beak should be compared with those represented in *l*, which is a drawing of the head and beak of a roseate spoonbill. A portion of the beak of the spoonbill carved in ivory is represented in *m*; this was taken from an altar of the same mound as the pipe.

Ivory was used to a considerable extent by the Ohio earthwork builders. The source of at least a part of it was the fossil tusks of the mammoth.

In *c* we have one of the simpler forms of pipes of this culture area. It is cut from a beautiful piece of green serpentine, and a large pearl was probably set in the cavity near one end. The finely formed pipe shown in *d* has the design *e* reversed upon the bowl.

A very unusual pipe from the Liberty group of mounds, Ross County, is illustrated in *f*, *g*. It is carved from a very compact brown stone. The neck and part of the head have been broken off. The opening to the bowl is through the mouth, and the smoke was drawn through a perforation in the neck.

[1] See W. C. Mills, Exploration of the Tremper Mound in Scioto County, Ohio, Holmes Anniversary Volume, pp. 334–358, pls. 1–5, Washington, 1916.

This carving probably represents the head of a snake priest, for a portion of the rattle of a serpent appears just above the swastika at the back of the head. This becomes clear upon comparing the design with one of the rattles in the tail of the conventionalized serpent shown in *i*, and also with that of the serpent monster illustrated in plate 11, *h*. The swastika, which in this instance is apparently a wind symbol, adds to the probability of this interpretation. The design upon the face doubtless represents facial painting. This is shown developed in *h*.

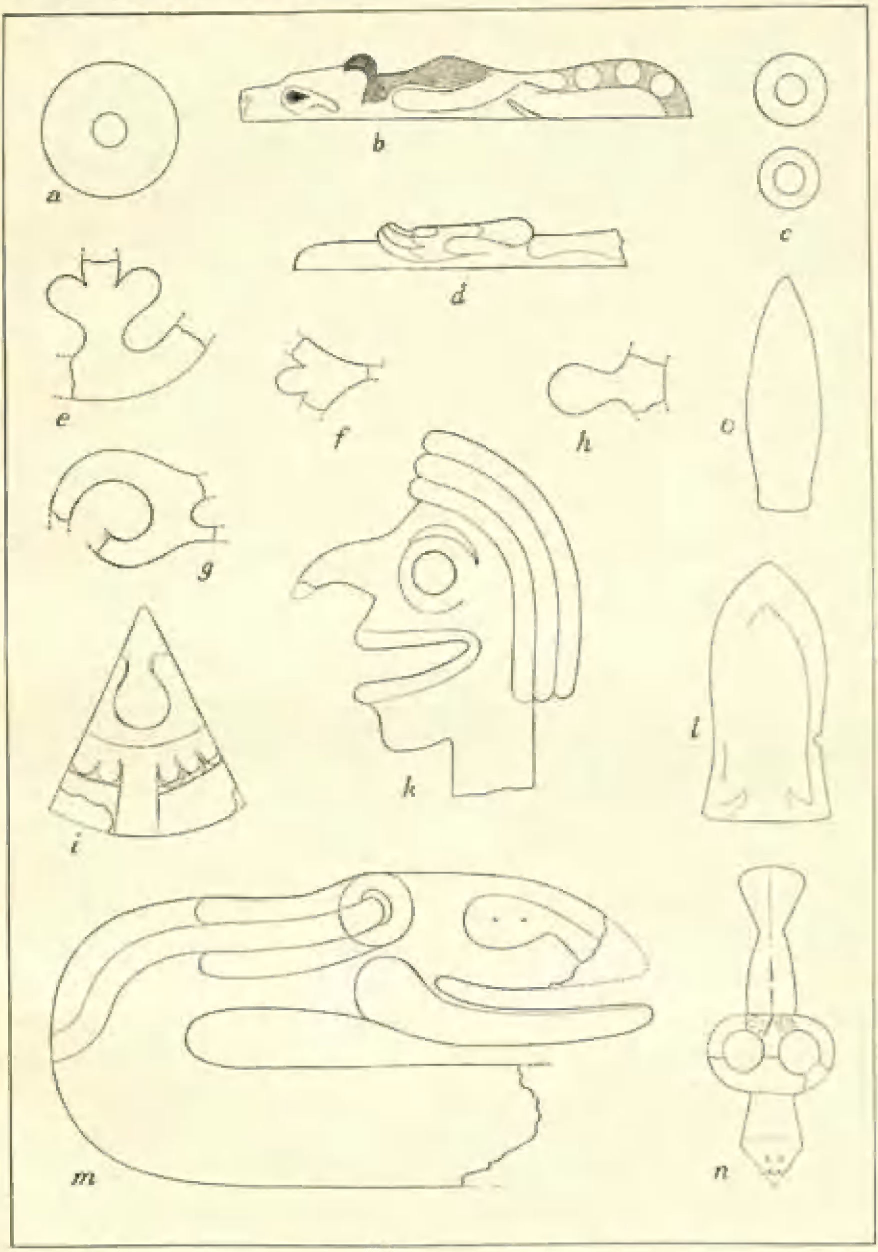
HOLLOW EFFIGIES.

Plate 11 shows a class of objects from the tumuli, the use of which is unknown. They are all hollow, and most of them are pierced by one or more holes. The walls of some of them are very thin, and considerable skill must have been required in their making.

An eared owl is represented in *a*. The notched beak, the ears which project upward over the eye, and the outline of the ruff extending backward and downward from the eye, are all characteristics of this bird. This is made of a stone resembling serpentine, and like most objects of this class is finely executed. Two other birds carved from antler are shown in *d* and *f*. The notched beaks seem to indicate that they were intended to represent hawks. The first was found upon an altar, and the second accompanied a burial in the great mound of the Hopewell group. The tadpolelike object (*c*) is made of serpentine; a part of a pearl still remains in the eye. It is probable that all of these effigies once had pearls inserted in their eye cavities.

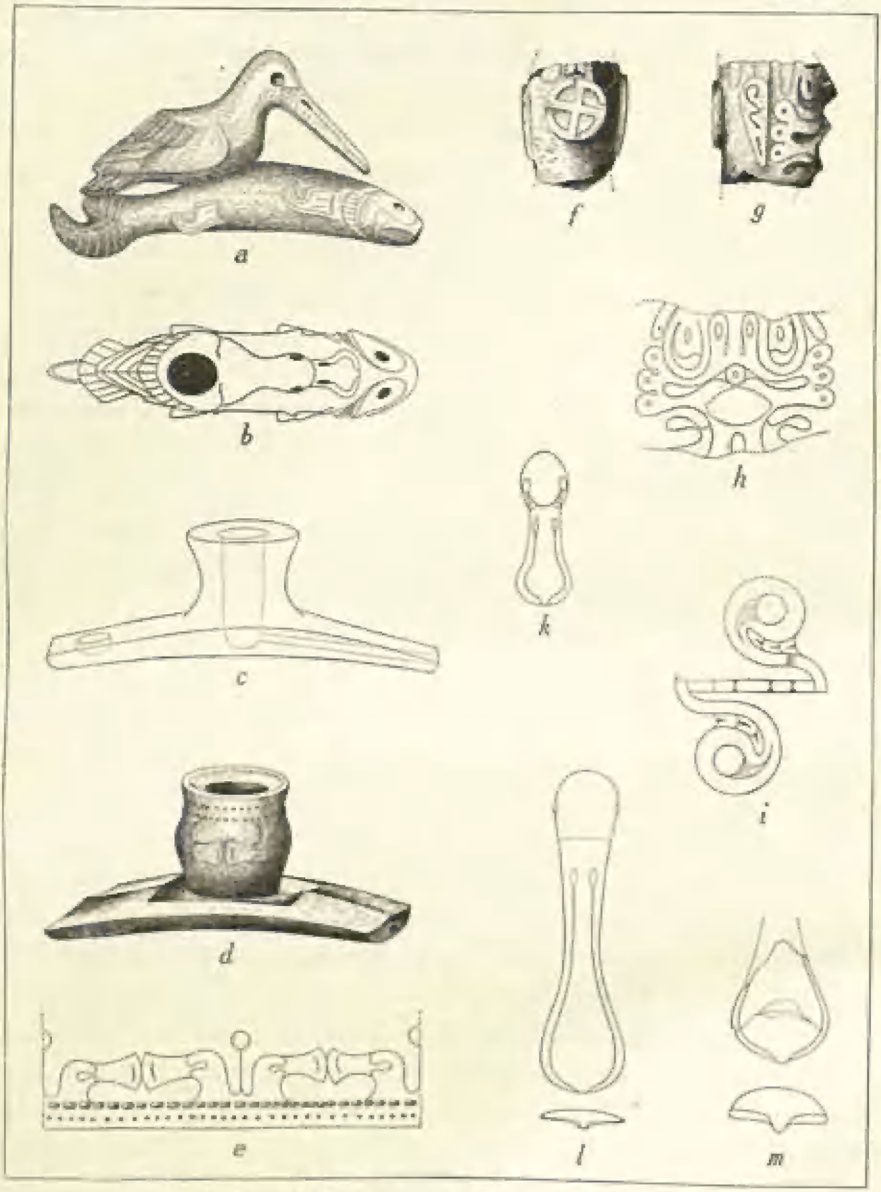
The beetle illustrated in *b* is carved in light-colored calcite and was taken from the group of mounds at Grand Rapids before referred to. What is perhaps the head of a doe is shown in *e*. This was obtained by Squier and Davis, and the drawing is from a cast in the Peabody Museum at Cambridge.

One of the most interesting effigies of this class is represented in *g*, *h*, *i*. This is carved in red slate and was taken from an altar of a mound of the Turner group. It was broken in many pieces, nearly all of which were recovered. This probably represents a mythical water monster analogous to those occurring in the mythology of the Pawnee and other tribes. It has the tail and head of the serpent. The plates of the serpent's head are shown above and below, and the four horns characteristic of the serpent deity north of Mexico are present. Two of the horns are carved in relief upon the top of the head, and two are made separately and inserted into holes drilled in each side. Like most effigies of this class, it is hollow, but the walls are not perforated.



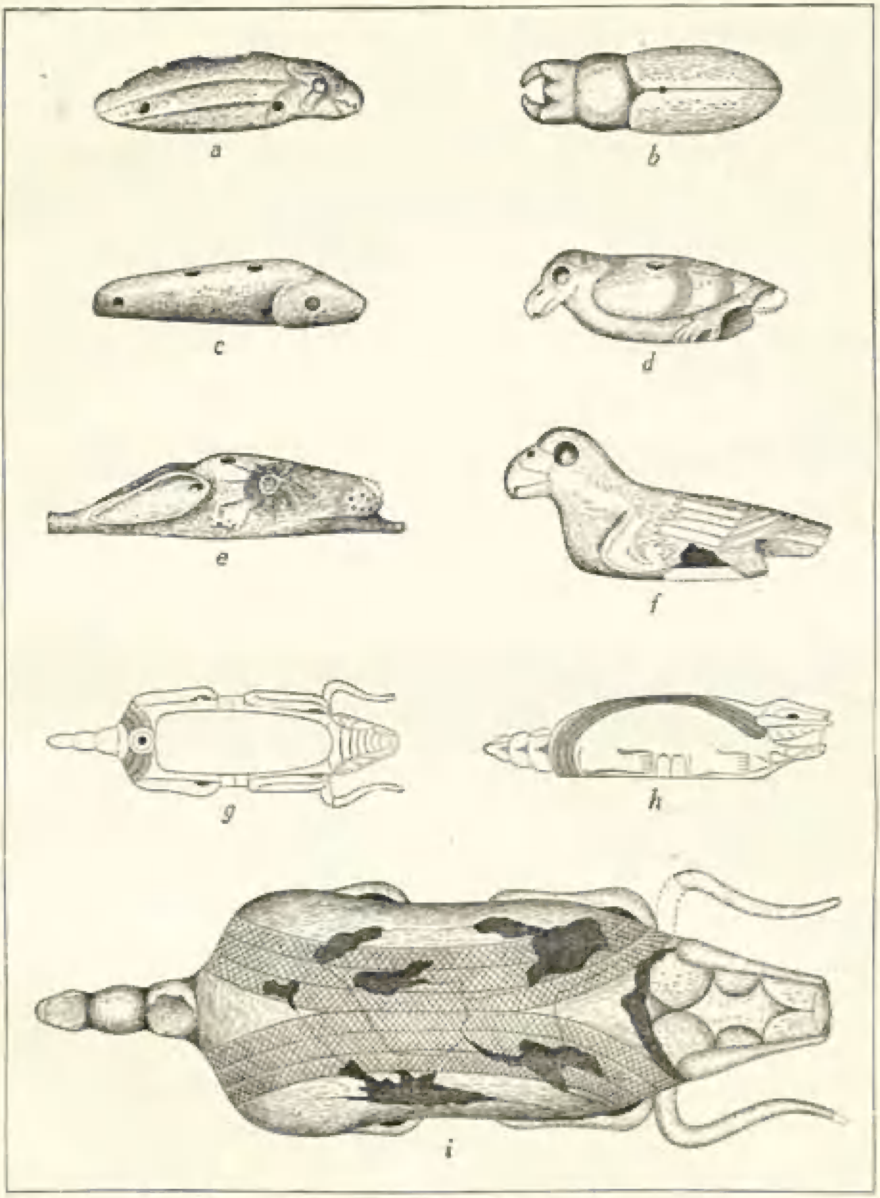
MICA OBJECTS FROM THE OHIO MOUNDS.

b, Upper portion of bear painted in colors; *e–h*, fragments of designs of the same character as shown upon plate 2; *l*, *o*, are in the form of flint knives or spear points; *m*, horned serpent; *n*, copy of atlatl, or spear thrower.



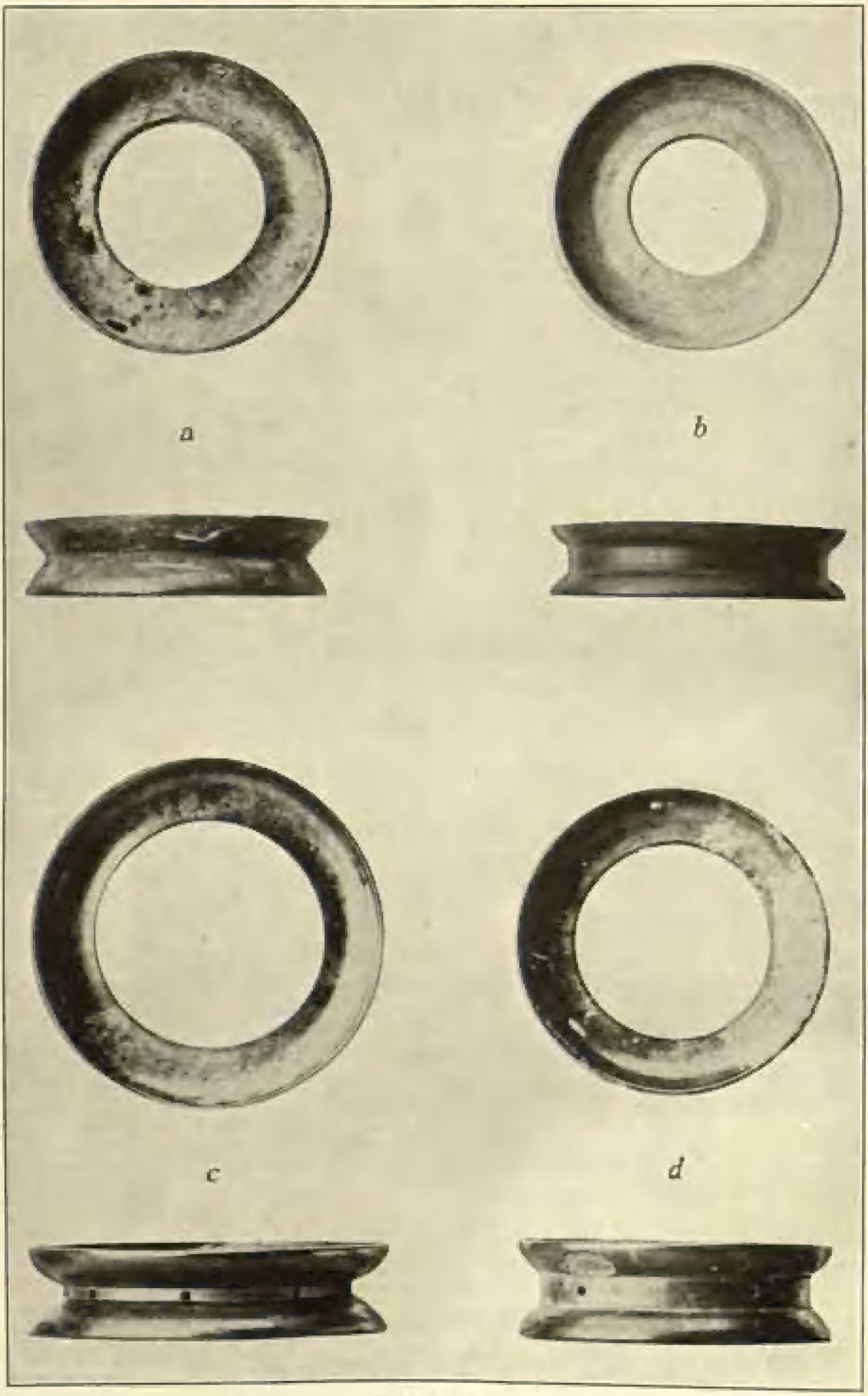
PIPES AND OTHER CARVINGS FROM THE MOUNDS.

a, *b*, *d*, *e*, *k*, Pipes from the Hopewell group; *c*, from mound in Michigan; *f*, *g*, broken pipe from the Liberty group; *h*, design upon face of *f*, *g*; *i*, developed serpent design upon stone ball from the Liberty group; *l*, head and beak of roseate spoonbill drawn from life; *m*, beak of spoonbill carved in ivory, Hopewell group. (About ½.)



HOLLOW EFFIGIES FROM THE MOUNDS.

a, c, d, f, From the Hopewell group; *b*, from a mound in Michigan; *i*, from the Turner group; *g, h*, two views of *i*, reduced. (About ½.)



STONE RINGS.

a, *c*, *d*, From the Hopewell group of mounds; *b*, made with primitive tools by the author. (About 2/3.)

STONE RINGS.

The beautifully formed stone rings shown on plate 12 *a*, *c*, *d*, and in cross section in figure 2, are among the most interesting objects recovered from the Ohio mounds. Similar rings were found by Squier and Davis and others. Those illustrated were taken, with fragments of others, from the altars of the Hopewell group.

These are probably ear plugs. Some of them are perforated laterally with four or eight holes as shown in the side views, *c* and *d*. It is not improbable that these perforations were for attaching feathers or other ornaments placed within or hanging from the central opening of the ring. Most of these are made from the brown micaceous mineral called "gold stone" by Squier and Davis, and are beautifully polished.

FIG. 2.—Cross-sections of rings on plate 12, *a*, *c*, *d*.

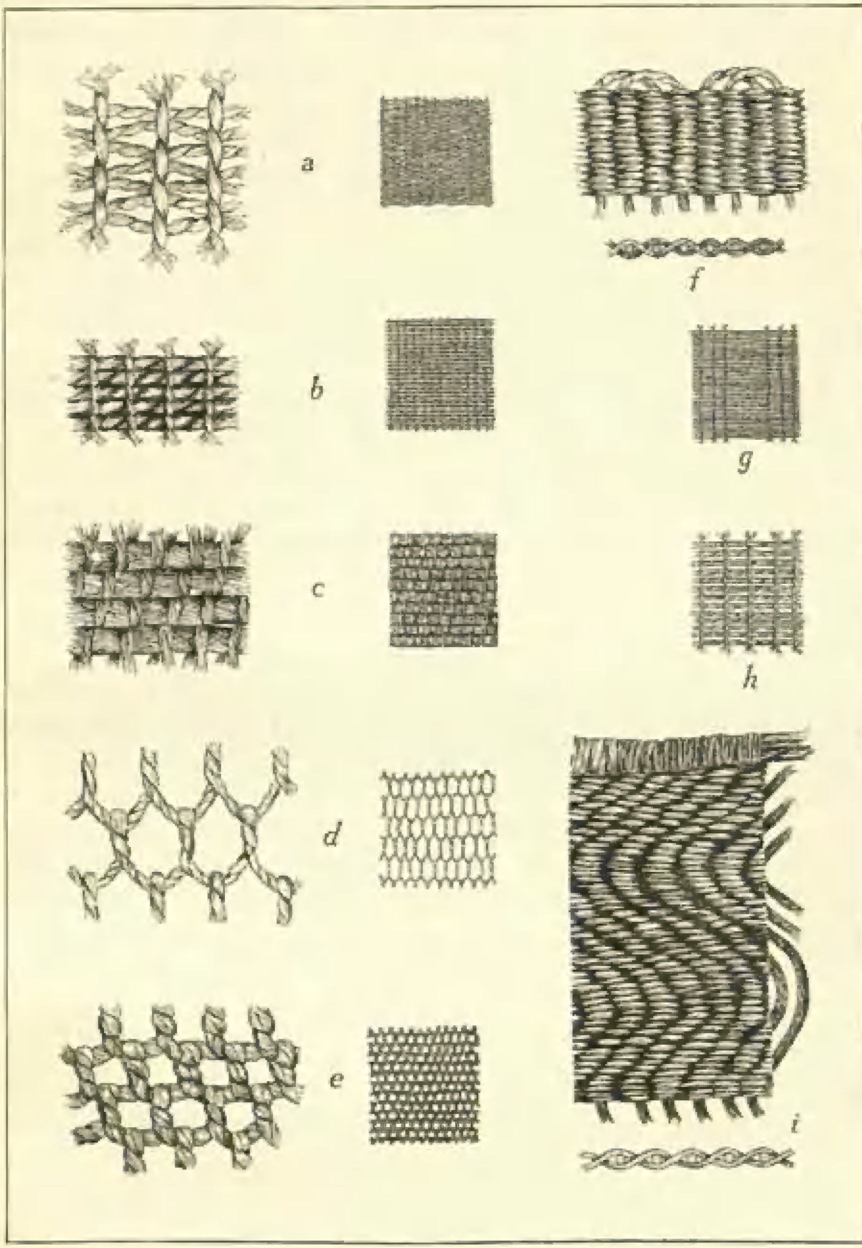
The most remarkable thing about them, however, is their symmetry. Their outlines form true circles and their surfaces are prefectly symmetrical. They could not have been made without some mechanical device based upon the lathe principle. The only other evidences of the use of the principle of the lathe by this people that I have been able to find is shown by a beautifully finished perforated disk of fossil ivory from a mound in Indiana and by certain shell beads that are altogether too symmetrical to have been made by any other known process. The fourth ring shown in the plate, *b*, was made by the writer from a piece of slate. The only implements used were stones such as may be picked up on almost any field, and two or three rude chipped knives. After roughly forming and perforating the slate disk, a stick about 6 inches long was fitted tightly in the perforation and its ends rounded and hardened in the fire. The stick was then placed between adjoining limbs of a tree, its ends being inserted in depressions cut into the limbs. With the aid of an improvised bow, the stick bearing the ring was revolved back and forth, and the ring finished by the use of the stone knives held against a crossbar. Sand, water, and ashes were used for polishing. The above device formed, of course, a rude lathe, but it was merely the adaptation of the bow drill which was known to the Eskimo and some other American tribes in prehistoric times.

TEXTILE FABRICS.

The textile fabrics of this people did not differ materially from those of many other tribes of the United States. They appear to be principally of the twined-woven variety which was so widespread

among people who had not adopted the loom. Many fragments of this cloth have been preserved by contact with metal objects, or have been found charred on the altars, or with cremated human remains. Some of this cloth is of a remarkably fine texture, for weaving done principally with the fingers unaided by mechanical devices.

Plate 13, *a–c*, shows small sections of twined-woven cloth at the right, at the left enlarged drawings of each which illustrate more clearly the relation of the warp and woof cords. Other examples of this weaving are shown in *g–i*. The wavelike arrangement of the warp cords in *i* is very unusual. The twined woof cords in all of the above specimens are relatively like those shown in the sectional sketch in *i*. In *f* we have an example of the simple in-and-out weave; this is probably a piece of the upper portion of a bag. This type of weaving was sometimes followed in this region in making much finer cloth. What appear to be fragments of netted bags are illustrated at the right in *d* and *e*. Enlarged drawings appear at the left, showing the stitch. This type of netting is found among the northern Athapascans, in California, in the Pueblo region, and in northern Mexico, but is rare in other sections north of Mexico.



TEXTILE FABRICS FROM THE HOPEWELL GROUP, OHIO.

a–c, g–i, Twined weaving; *f*, in-and-out weaving; *d, e*, netting. (Drawings at the left, *a–e*, are enlarged;) all others about ($^1/_2$.)

A HALF CENTURY OF GEOGRAPHICAL PROGRESS.[1]

By J. Scott Keltie, LL.D.,
Late Secretary of the Royal Geographical Society, London.

[With 2 plates.]

When I was honored with a request from your council to open this new session of the Royal Scottish Geographical Society, by a lecture on geographical progress during the last half century, I am afraid I accepted the invitation with a light heart. It was only when I began to face the subject that I realized its magnitude. To do it justice would take volumes. In the brief space of a lecture I can only hope to indicate succinctly the lines upon which the main advances have been made; to bring before you an impressionist picture, marked, it may be, by some of the bewildering confusion characteristic of that evolution in the domain of art. * * *

First of all, it may be useful to make it clear to ourselves what is the field covered by the subject, the progress of which during half a century it is our task to trace. I think for our purpose we may regard geography as the science which deals with the distribution of the features of the earth's surface and of all that it sustains, mineral, vegetable, and animal, including man himself. In fact, man is the ultimate factor in the geographical problem, the final object of which is to investigate the correlations which exist between humanity and its geographical environment. It is evident, then, that before the geographer is in a position to apply scientific methods to the problem which it is his function to solve he must first have an adequate knowledge of the data which form the terms of the problem. Such data can only be obtained by the exploration of the earth's surface conducted by scientific methods. Therefore in attempting to review the progress of geography during the past half century, our first task is to ascertain what have been the main additions to our knowledge of the earth's surface by means of exploration. Secondly, we should endeavor to ascertain what progress has been made in our methods of dealing with such results. Has there been any marked

[1] An address delivered before the Royal Scottish Geographical Society in Edinburgh on Nov. 18, 1915. Reprinted by permission from the Scottish Geographical Magazine, December, 1915.

advance in the application of scientific methods to geographical problems? Thirdly, what improvement has been introduced into geographical education?

In attempting to take stock of the results of the exploration of the unknown and little-known regions of the globe during the last half century, starting for convenience with the year 1860, I think it is safe to say that we have to go back to the half century which followed 1492 (when Columbus stumbled on a new world) before we find a period so prolific. The two poles have been reached and large additions made to our knowledge of the polar regions. The unknown two-thirds, at least, of the Dark Continent have been more or less provisionally mapped, and all but an insignificant fraction partitioned among the powers of Europe. Great areas of North America have been surveyed and occupied, while much has been done for the exploration of Central and South America. The map of Asia has to a large extent been reconstructed, while the vast unknown interior of Australia has been traversed in all directions. Even much of Europe has been resurveyed. A new department of science, oceanography, has been created as the result of the *Challenger* and other oceanic surveys. But let us deal with the subject in somewhat more detail, beginning at the north.

The leading episodes that have marked the progress of exploration since 1860 must be within the memory of many of you, though probably few of the audience can go back to the forties and fifties as I, alas, can do. But time will not permit of my dealing in detail with the episodes that have marked the progress of discovery, only with the results.

What, then, has been the result of all the half century's strenuous efforts to unravel the secrets of the lands that fringe the great ice-bound ocean around the North Pole. In 1860 the north coast of Greenland had never been reached, and the east coast beyond 65° north was only known in patches. Our knowledge of the Arctic archipelago was greatly defective. What lay between Spitzbergen and Nova Zembla was entirely unknown; the coast of Siberia was imperfectly mapped and the seas beyond largely unexplored. No soundings had been taken in the Arctic Ocean, and the farthest north reached was a little over 82°, a latitude reached by Hudson some 300 years ago. Now Greenland, largely through Peary's work, has been extended to over 83° north, and the whole coast has been practically charted: the Arctic Archipelago has been greatly extended; Franz Josef Land has been placed on the map; a large island has been discovered to the north of Siberia and another on the west of the Arctic Archipelago; great additions have been made to our knowledge of Spitzbergen and Nova Zembla; depths of 2,000 fathoms have been sounded in the Arctic Ocean; and the North Pole

itself has been located amid thick-ribbed ice. Besides these geographical discoveries, substantial contributions have been made to other departments of science which enable us to understand better the régime of these inhospitable regions in the general economy of our earth. There still remains much to be done, especially in the wide region to the north of Bering Strait, before our knowledge is complete.

Turning to the other end of the earth, there is a great gap between the work of Ross, Wilkes, D'Urville, and Bellingshausen, and the outburst of enterprise in the exploration of the Antarctic continent in quite recent years. Borchgrevink and the Belgians under Gerlache began the campaign some 18 years ago. But undoubtedly the first organized attempt on a great scale to scatter our ignorance of a continent as large as Europe, though probably of little use to humanity, was made by the great expedition under Capt. Scott, whose tragic and heroic death with his four companions some years later places them high up on the nation's roll of honor. Amundsen, who discovered a new and easy route, rushed in and reaped the fruits of the 10 years' labors of these indomitable British explorers. Then there is Drygalski's expedition, and we have Bruce, Shackleton, and Mawson (from Australia) and Charcot on the Graham Land side. John Murray saw the land from the *Challenger* in the seventies, and with his usual insight surmised that here lay a great continent. Before the campaign began the only big gap was that made by Ross in the Ross Sea and along the great ice barrier, with somewhat hypothetical patches elsewhere. Now, it may be said truly that in the period with which we are dealing, and especially in the last 18 years, enormous additions have been made to our knowledge of the outline, and even a large extent of the interior, of the most repellent land on the face of the earth. It may be said that with Ross's discovery as a basis within the last 15 years the whole coast line of the Antarctic continent has been laid down from King Edward VII Land to Kaiser Wilhelm Land, considerably more than a quadrant of the circumference, and that from the observations which have been made the interior is a lofty ice-covered plateau, bordered in parts by still higher mountain ranges, with indications that in past ages a climate favorable to temperate or even subtropical vegetation must have existed. The meteorological work carried out, especially by Mawson's expedition, may turn out to be of practical service to meteorology in general and to that of Australia in particular. In the interests of science at least, it is hoped that the entire outline of the Antarctic Continent will be laid down and further investigations carried out sufficient to satisfy our natural curiosity as to the past history of this great ice-bound land.

As a contrast to the frigid regions with which we have been dealing, let us turn to the most tropical, and in 1860 the most unexplored of all the continents, Africa. One of my earliest geographical recollections is of a map of Africa somewhere in the forties and early fifties on the wall of the school of my boyhood; begrimed and faded, with the word "unexplored" in large capitals, from the Sahara to the borders of the Cape. I am afraid we boys were not sorry for the great blank without a single name to plague our memories.

As represented on the best maps of 1860, Africa from about 10° north to about 20° south, was mainly a blank, checkered here and there with conjectural and imaginary features. Livingstone and Burton and Speke had been at work. We see the course of the Zambezi laid down, and vague indications given of Lake Tanganyika, Victoria Nyanza, and Lake Nyasa. The Nile is timidly brought down in dotted lines toward the Equator. A little bit of the lower Congo is shown with many dotted lines of conjectural tributaries joining it from various directions, but no indication given of its real course. Our positive knowledge was comparatively infinitesimal. It is not too much to say that of the 11,000,000 square miles of Africa something like 6,000,000 was practically unknown, and of the remaining 5,000,000 probably not more than 1,000,000 was mapped with anything approaching accuracy. The real inspiring initiative of the modern exploration of Africa undoubtedly rests with David Livingstone, who in the fifties led that ever memorable expedition across south-central Africa which placed the great Zambezi for the first time throughout its length upon the map.

But it is impossible to follow in detail the work of the multitude of explorers who, since 1860, have entirely changed the face of the no longer "Dark Continent."

The work of the great army of explorers during the half century has changed the face of the continent and filled up the enormous blanks that disfigured the maps of 1860. While the outline of the coast remains as rigid as in the old maps, unindented by any of those great oceanic intrusions which mark the other continents, exploration has revealed a surface much more diversified than the geographers of two generations ago would have led us to expect; while the interior is mainly of a plateau character, the borderlands all around are more or less mountainous, with peaks rising in certain cases to heights approaching 20,000 feet. It has four great river systems and many subsidiary basins; a profusion of lakes, abundant forests, and park lands, and open areas that may be turned to the uses of humanity. Even the greatest desert in the world, the Sahara, has its mountain ranges and lofty plateaux, sometimes snow clad. Unfortunately the abundant water-supply is not well distributed, though even the Sahara and the Kalahari have underground stores which

may yet be utilized with good results. We have found that the continent is not nearly so hopeless as was believed from the standpoint of European settlement and enterprise. The white man has learned better how to adapt himself to tropical conditions, while there are many regions with altitudes that afford a climate in which the European can live in comfort and wholesomeness. Still, so far as we can see at present, the resources of the continent must be developed mainly by native races under the guidance of their white brothers.

As to these white brothers, we must next consider the areas that have fallen to the share of the various European powers. The scramble, which may be said to have begun when Stanley went out for the King of the Belgians to annex the Congo in 1879 and was virtually completed in 1886, has culminated in the absorption of the whole of the continent, except Abyssinia in the east and Liberia in the west. Britain has no need to be dissatisfied with her share, which now includes the whole of Egypt and the Egyptian Sudan. * * * Britain's share amounts to 3,500,000 square miles, with a population of 53,000,000; France to 4,500,000 square miles, with a population of only 42,000,000; and Germany 1,000,000, with a population of 12,000,000. The rest belongs to Portugal, Spain, Liberia, and Abyssinia. Of the total trade in 1914 Britain claimed £155,000,000 (of which 90,000,000 were exports), or two-thirds, leaving only one-third to the other powers.

Much still remains to be done before our knowledge of the geography and economic potentialities of Africa can be regarded as adequate. A great network of routes and more or less provisional surveys have been laid down all over the continent, but the broad meshes between these lines have yet to be filled in. To accomplish this satisfactorily we require the services of specialists trained to scientific investigation in the various departments of science on which geography, in its broadest and highest aspects, is based, for it is only as all the raw material from all over the surface of our globe is brought together and systematically arranged that the geographical student will be in a position to work out the many problems, physical and human, with which his science has to deal.

I fear I must treat America with brevity. In the most popular American textbook of geography a few years before our half century it was gravely stated that the Alleghenies of North America were the continuation of the Andes in South America. Half a century ago much of the region west of Lake Ontario in the north and of the Mississippi in the south was the home of the Indian, the trapper, and the buffalo. Canada consisted still of Upper and Lower Canada; Victoria on Vancouver Island was only a Hudson's Bay Co.'s post; and so was Fort Garry, now the great city of Winnipeg. Vancouver City did not exist. How Canada has since pushed westward you all

know. Winnipeg, Vancouver, and Victoria are flourishing cities; the whole habitable country has been more or less explored and provisionally mapped, partly by individual explorers but mainly by the Canadian Survey; waving fields of wheat have taken the place of the rank grass of the prairie; great cattle ranches reach to the foot of the Rocky Mountains; coal mines are being worked in the east and west. The area of settlement and of agriculture has been pushed some degrees farther north and northwest; the British Atlantic has been connected with the British Pacific by railways which make Britain independent of all foreign routes.

The caterpillar shading which indicated the Rocky Mountains from Alaska to California has given place to complicated ranges, with characteristic buttressing features, great plateaus with many offshoots, and beautiful coast ranges. All the vastly increased knowledge of Canada has led to the development of its resources at a constantly increasing rate. The whole country has been united into one great Dominion, divided into many Provinces, in place of the Upper and Lower Canada of half a century ago. The population has increased from 3,000,000 to over 8,000,000, but Canada is capable of sustaining ten times that number. Over 110,000,000 acres of land are occupied, and of this 10,000,000 acres are under wheat and an equal area under oats. The annual value of the mineral products alone amounts to about 30,000,000 sterling, and of manufactures to 240,000,000 sterling, while the total exports approach closely to 100,000,000. I give these figures as affording some idea of the vast progress made by Canada in the half century in expanding this great country and obtaining a knowledge of its resources. But there is ample room for still further exploration and development, and more detailed and accurate mapping; during the next half century the progress achieved must be much greater than in the past.

What Canada has done in the north the United States has done on a much greater scale in the south—naturally so, when one considers the difference in climate over the whole area. Not to mention the work of individual explorers, the survey men have penetrated into the remotest regions; have told a wondering world of the canyons of the Colorado, those 5,000-feet-deep gorges which are matchless specimens of nature's sculpture; of the gorgeous beauties of the Yellowstone Park; the witcheries of the Yosemite; the great deserts which the coast ranges deprive of moisture; and the Rocky Mountains themselves with their picturesque peaks and rich upland parks.

As a result of all this activity the whole of the 3,500,000 square miles of the Republic has been occupied; with the exception of remote Alaska, all the old Territories have been organized into States; the population has risen from 30,000,000 to over 100,000,000;

excluding Alaska, 1,300,000,000 acres of the total 1,900,000,000 acres have been appropriated and reserved. These figures may afford some idea of the activity of the United States during the half century in exploring its enormous territory and taking stock of its resources.

As to South America, it was in 1860 that Bates returned, after 11 years' sojourn in the Amazon Basin, mainly as a naturalist, but with abundant fresh information on the geography of that enormous river basin. Since that time a host of explorers—British, French, German, American, Swedish—have penetrated into the recesses of the continent, exploring its multitude of rivers, climbing and mapping the great Andean Range, investigating the interesting antiquities of the continent, studying its natives of many types, and reporting upon its resources. The Argentine and Chile, the two most advanced of South American States, have surveyed and mapped, at least provisionally, their extensive territories, while boundary commissions have added much to our knowledge. The result is that the map of South America is very different from what it was half a century ago. Still, it must be said that more remains to be done in the way of pioneer exploration in South America than in any other continent except the Antarctic. At least 1,000,000 square miles are practically unexplored, while a large area of the remainder is imperfectly known. In the northern basin of the Amazon very much still remains to be done. A vast extent of the great forest area of Brazil has never been penetrated. Maj. Fawcett in a recent exploration in the Bolivia-Brazil border came across a forest tribe that thought themselves the only people in the world except a hairy tribe some miles away. In Venezuela, Colombia, Ecuador, and even in Peru and Bolivia great areas are all but unknown; even the interior of the Guianas has never been adequately explored; and very much remains to be done before the magnificent chain of the Andes can be regarded as sufficiently mapped. South America has been attracting increased attention in recent years, and it is to be hoped that in the near future serious attempts will be made to complete our knowledge of a continent teeming with features and races of interest, and the abundant resources of which are capable of vast development.

If now we turn to Australia we shall find that as much heroism, endurance, and self-denial have been displayed in the exploration of the interior of that great southern continent as there has been in the case of Africa. Half a century ago we knew little more than the rim of the continent. Men could only wonder what lay in the unknown interior; was it picturesque mountains, flowing rivers, great lakes, luxuriant forest and pasture lands, or was it only a southern Sahara? During the last half century the Australians have made the most

strenuous and praiseworthy efforts to discover the characteristics of this great continent of which they are the stewards. All the Australian States have for years had well-organized surveys at work, and New South Wales and Victoria are now fairly well mapped, and their features and resources known.

One of the great episodes in Australian exploration is the terrible disaster that befell the Burke and Wills expedition which, in 1860-61, actually crossed the continent from Victoria by the Stony Desert and the Mackinlay Range to the estuary of the Flinders River in the Gulf of Carpentaria; the two leaders paid for their zeal with their lives. Much more successful was Macdouall Stewart who, in 1862, after two previous attempts, crossed the center of the continent from Adelaide to Port Darwin along the route now occupied by the trans-Australian telegraph line and the transcontinental railway now under construction. He brought back good news of fine ranges of hills, grassy plains, and fair supplies of water, and altogether gave the Australians new hope of their continent. About the same time two other expeditions crossed the continent from north to south and south to north, in search of Burke and Wills, adding much to our knowledge of Queensland. The Stony Desert of Sturt was found flooded with water, and all around its borders were rich pasture grounds.

The general result of the many exploring expeditions in the eastern half of Australia has been to show that while there are great patches of desert there are extensive areas of excellent country which would be as valuable as the finest land in Europe if only the rainfall could be depended upon; but away from the coast you can not expect 10 inches a year; occasionally there may be more, but sometimes also much less.

Still, about the western half of the continent nothing was known, though in the north and northwest various expeditions had found rivers and plateaus and hills, and the country in the immediate neighborhood of Perth and along the west coast was fairly well surveyed. The first successful attempt to cross from east to west was made in 1873 by Col. Warburton, who, with his son, some natives, a few Afghans, and a troop of camels, started from the center of the continent and crossing mainly between 20° and 22° south latitude reached the De Gray River after terrible sufferings through want of food and water. Nothing marked their dreary way but a desert of sand hills and spinifex, with here and there a scanty water hole.

Since then the continent has been crossed and recrossed in all directions by Forest, Giles, and their successors. The discovery of gold in Western Australia led to further exploration of that territory and an influx of immigrants adding greatly to the scanty popu-

lation of half a century ago. All these expeditions, combined with the official surveys, have afforded a fair knowledge of the main features of the interior, which are much more varied than was at one time supposed. At the same time, the numerous rivers shown on the map in central and western Australia lack that permanency which is necessary for successful agricultural operations. But great schemes are on foot for irrigation and storage, and, as is known, the immense underground supply of water has been tapped, though, as it is not unlimited, its use ought to be carefully regulated. The population during the past half century has trebled, and the material progress during recent years has been so great that the Imperial Government felt justified in combining the various colonies into one great commonwealth. Under this new régime there is no doubt that a much more detailed exploration of the continent on scientific lines will be carried out in future, with beneficial results on its development, mineral, agricultural, pastoral, and manufacturing. In the annual production and commerce of the Commonwealth gold has ceased to be the most important factor. The agricultural production alone amounts to about 50,000,000 sterling, the pastoral to close on 60,000,000, while dairying products yield 20,000,000 and manufactures 58,000,000. Mining products amount to some 25,000,000. The total exports are now almost 80,000,000, and of that wool alone is valued at over 26,000,000.

This will afford some measure of the extent to which Australia has been explored during the past half century. When we remember what man has been able to accomplish in older countries by tree-planting, irrigation, and other judicious methods, there is no need to despair of Australia. At the worst there is plenty of room for the hundred millions which it is estimated—by Australians—will be the population of the continent a century hence. We may be sure there is a great future in store for our southern dominion, with British energy to make the best of geographical conditions.

Although New Guinea, especially the spacious western section belonging to Holland, remains one of the few regions which affords ample scope to the adventurous pioneer explorer, still, much has been done in recent years to furnish a fuller knowledge of its interior, especially since the narrower eastern section was annexed by Great Britain and Germany. Half a century ago it was practically a blank. Into the discoveries that have been made in that magnificent archipelago that fringes southeastern and eastern Asia I can not enter. Much has been done in the Philippine Islands and in Formosa by the United States and Japan, to which respectively these islands now belong. Though many additions have been made to our knowledge by British and Dutch explorers in the other islands

of the great Asiatic archipelago, still much remains to be accomplished, especially by the scientific explorer.

As for New Zealand, its exploration during the last half century has been carried on mainly by its well-organized survey, so that it is now to a large extent well mapped, while the peaks of its picturesque mountain ranges have been ascended by many Alpinists, with the result that the map of what is now the Dominion of New Zealand is very different from that of half a century ago. The development of its resources has kept pace with the progress of exploration, so that the value of its exports have reached the amount of £23,000,000, mainly wool, agricultural and dairy products. The population has grown from a few thousand in 1860 to over a million.

As for the great continent of Asia itself, the primitive home of the human race, according to some, and therefore the longest known of all the continents, I can barely touch it. Unlike Australia and the New World, its great features, its matchless mountain systems, its magnificent rivers, its spacious table-lands, its sandy deserts, have long been known in their main features. But during the last half century very much has been done to fill in the details of these features and give them precision. War and conquest have here been the great handmaids of geography. In our own great Asiatic dependency—India—we have acted on the wise principle that to govern a country well, you must know it well. One of the greatest enterprises ever undertaken by any Government has been brought to a completion during the half century. Nothing is more creditable to us in our connection with India than this great trigonometrical survey, begun about a century ago and completed quite recently. We have measured every mile of the country; we have plotted all its mountain systems, laid down the courses of its mighty rivers, mapped its deserts and its forests and its great alluvial plains, which now form one of the great wheat granaries of the world. Many of the towering peaks of the Himalayas have been measured in their heights, and some of them scaled, and those grand glaciers, which the great Humboldt declared could not exist, have been explored and mapped; the meteorology of the peninsula, on which so much depends, has been and is being worked out on a magnificant scale, while the Geological Survey has done much to unriddle the evolution of India and reveal its mineral treasures. Our wars with Afghanistan have enabled us to map partially at least that troublesome country. Our explorers, some of them native Indians, some of them Britons of the fine old adventurous type, have faced many dangers, penetrated into nearly every corner of central Asia, and brought back treasures in the way of knowledge. But all around our Indian borders our modest military expeditions have always been accompanied by surveyors, British and native, who have generally returned with a rich

harvest of geography. Only quite recently the age-long problem of the Sanpo-Brahmaputra has been all but solved by the enterprising son of the society's late secretary, Capt. Eric Bailey, when some thousand or two square miles of the region were surveyed and mapped. Burma and the Malay States are being surveyed; Siam has been mapped, while similar services are being rendered by France in the territories under her domination. Partly through the enterprise of individual travellers and partly as a result of Sir Francis Younghusband's expedition, Tibet and Lhasa are no longer the mysteries that they were, and the great Brahmaputra has been traced to its source. Sven Hedin, confirmed the existence and explored the great range beyond the Himalayas conjectured to exist by Trelaunay Saunders as far back as the seventies.

But I can not attempt to record the work of individual explorers. The High Pamirs have been fully mapped. The Kuen Lun, the Tian Shan, and these other great ranges that lie between Tibet and Turkestan and southern Siberia have been plotted in their main features. The Gobi, the Takla Makan, and other desert regions have been explored, as has the Tarim basin and the shrinking lakes scattered about in the eastward, while many of the marvelous remains of ancient cities and towns have been discovered. The upper courses of the great rivers, the Hwang, the Yangtze, and others flowing to the south that rise in the region of the northeast of Tibet have been approximately mapped. Progress has been made in the accurate mapping of China, though much still remains to be done in this interesting land. Japan has been as well mapped as India. Our knowledge of Mongolia and Manchuria have been greatly increased; this has also been the case with Siberia, through the surveys for the Trans-Siberian Railway which has made it possible to reach Japan and Pekin in about a fortnight from London. Southern Siberia itself, it has been found, may compare with Canada as a wheat-growing country. In central and northern Siberia much still remains to be done, especially in connection with the hydrography of its great Arctic-flowing rivers. To the ever-progressing conquests of Russia we owe much of our knowledge of Central Asia. Half a century ago her borders scarcely extended beyond the Caspian shores. Little by little her explorers traveled east and north and south, followed by her armies, until she marches with China, and is within measurable distance of India. The ancient Oxus has been traced to its source, though problems remain in connection with its old channels and the fluctuations of the Aral and Caspian, and the conditions of ancient civilization in these regions. We know a good deal more about Persia than we did half a century ago, though there is much room here for the investigations of the qualified explorer, especially as to the present and past conditions of the Lut desert. Just half a century

ago Palgrave succeeded in crossing Arabia. Various explorers have been at work since then in the west, the north, and the center. Quite recently it was crossed again in the opposite direction from Palgrave's route by Capt. Shakespear, who, alas, a few months ago laid down his life in the interests of the empire. But for the pioneer Arabia still presents a fruitful field, especially in the great southeastern desert, which is practically unknown. While Palestine has been adequately surveyed and accurately mapped by the Palestine Exploration Fund, and much geographical and archeological work done in the rest of Turkey-in-Asia, there is much of interest still to accomplish here by the well-trained explorer. While, therefore, the map of Asia has to a large extent been reconstructed during the last half-century, it has, with certain exceptions, been mainly the work of pioneers. There is ample room for accurate work all over the continent, especially with the various historical and economic problems dealing with the distribution and grouping of different physiographical and animate types, in which Asia abounds perhaps more than any other continent.

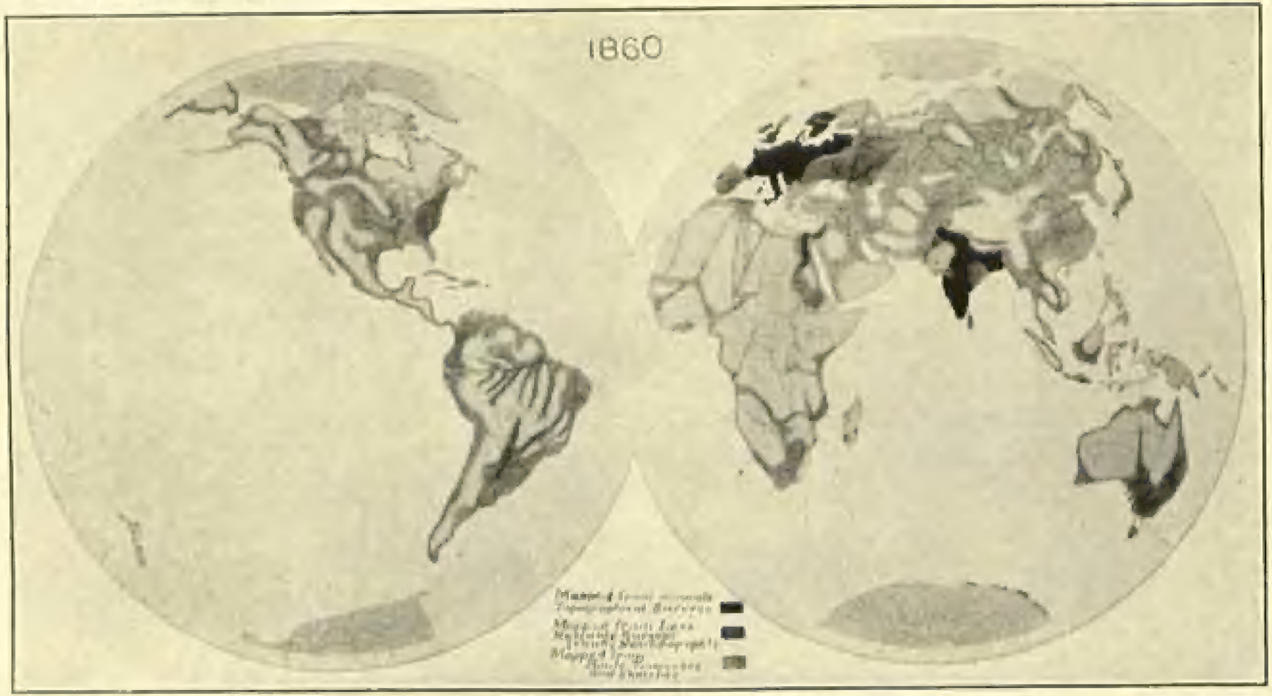
It is more than half a century ago since Mrs. Hemans asked the question—

> "What hid'st thou in thy treasure caves and cells,
> Thou hollow-sounding and mysterious main?"

The question has been answered to a large extent by the deep-sea researches of the last 50 years, and on the basis of these researches a new department of science has been created under the name of oceanography which has now plenty of work to do. There have been numerous expeditions whose main purpose has been to explore the ocean from its surface to its deepest depths, but undoubtedly the greatest of them has been that which for three years sailed all over the oceans in Her Majesty's ship *Challenger*. The ocean has now been sounded in thousands of places, specimens of its bed have been brought up and analyzed; its denizens have been captured and brought to the light from all depths; its saltness and its temperature have been tested in all quarters of the globe; its surface and undercurrents have to some extent been charted; and in every way it has been subjected to the never-satisfied curiosity of humanity.

It would be hopeless for me to give you anything like a satisfactory summary of the results.

As to depths, I may say that the average depth of the Pacific is something like 15,000 feet and of the Atlantic 12,000 feet. The greatest depth yet found in the Pacific is 31,614 feet, off the Marianne Islands, while in the Atlantic the deepest trustworthy sounding is 27,366 feet, near the Virgin Islands. The waters of the ocean seem to be in a state of constant circulation, cold undercurrents coming down from the poles and warm surface currents going south and north in



THE WORLD IN 1860, SHOWING EXTENT TO WHICH IT HAD BEEN SURVEYED AT THAT DATE.

From a map supplied the writer by Mr. E. A. Reeves, Map Curator, Royal Geographical Society.

THE WORLD IN 1915. FOR KEY SEE PLATE 1.

From a map supplied the writer by Mr. E. A. Reeves, Map Curator, Royal Geographical Society.

return. One of the best known of these great ocean currents is the Gulf Stream, about the régime of which popular ideas have had to be considerably modified. As to the distribution of life in the ocean, researches of the *Challenger* and other similar expeditions have disclosed thousands of new forms in all seas and at all depths of the ocean. There does not seem to be any part of the open ocean so deep, so dark, so still, or where the pressure is so great as to have effectually raised a barrier to the invasion of life in some of its many forms. Even in the greater depths many divisions of the animal kingdom are represented.

We have had revealed to us from these hidden depths great, broad valleys, spacious plateaus, gently undulating ridges rising here and there into mountains, whose peaks overtop the water in the shape of the islands that stud the bosom of the sea, with here and there precipitous gorges covered with the débris of the myriads of animals that have found a home and a grave in those waters during untold years.

I need hardly remind you that the many island groups which stud the bosom of the spacious Pacific have, like Africa, been parted among the powers of Europe, as well as the United States, with the result that much has been done to add to our knowledge of the islands and their vanishing peoples.

The accompanying maps will show roughly by different shading the progress which I have tried to outline in the exploration of the globe during the half century. (Pls. 1 and 2.)

The raising of the standard of geography during the last 30 years and the increasingly rigid application of scientific method to geographical research and to the practical application of its results has had considerable effect on the organization and equipment of exploring expeditions, and of the type of men selected to carry out exploring work. So long as a great part of the world was very much of a blank we welcomed any authentic information that could help to fill it up, even though the explorer was a pioneer without any special training. But now that the main features have been filled in with varying degrees of accuracy we must insist that explorers shall have a training adequate to the conduct of their work on scientific lines. Dr. de Filippi's recent expedition to the Karakoram may be taken as a model of what the expedition of the future should be, with its ample staff of specialists in every department of science involved in the work the expedition had to accomplish, and its complete equipment with the latest instruments necessary to give the most satisfactory results. But this condition has been increasingly recognized in recent years.

This is the place to refer in a word to the great service rendered to exploration, and to geography in general, by photography since it began to be applied to this purpose. The old wood engravings, and even plates, which were used for illustrations in the prephotographic days, while sometimes wonderfully good from the artistic, and even from the geographical standpoint, could seldom compete in the latter respect with the photographs taken by a discerning eye. I remember well the difficulty in persuading some of the more conservative members to permit the introduction of lantern slides at the meetings of the Royal Geographical Society as being too trivial and too childish for a serious scientific body. I need not remind you of the universal use now of this method for scientific lectures of all kinds.

One other feature which has marked the development of geographical work during the half century might be pointed out. Fifty years ago geographical enterprise was the work of individual explorers, sometimes backed by their Governments; but in recent years a remarkable circumstance in geographical method has been the growth of international cooperation, as shown in the international congresses and international bodies, such as the International Geodetic Association, the International Meteorological Committee, the International Council for the Study of the Sea, with special reference to fisheries; the international map of 1:1,000,000; and the great bathymetric map of the oceans undertaken by the Prince of Monaco with an international committee.

I have thus endeavored to present to you, I fear in a very summary fashion, the results which have been achieved during the past half century toward the completion of our knowledge of the home of the human race. I think you will admit that so far as results are concerned it will compare favorably with any other half century in the history of exploration. I have had necessarily to confine myself to what I may call the superficial results of all this activity. But apart from the fact that vast areas of previously unknown lands have been brought within human ken and provisionally mapped, abundant additions have been made to all the aspects that come within the sphere of geography. Many departments of science have profited by these explorations—the character and distribution of physical features of minerals and vegetation, of animal life, of climatic and economical conditions, of man himself in his various races and varieties. Of some of the results of all this knowledge you may have been able to form some idea from the figures I have given as to the growth of the population and the greatly enhanced value of the results of economic development. For the more detailed and precise is our knowledge of the habitable lands of the globe the more are we in a position to turn them to the best account for the benefit of humanity. As I have pointed out, there is still a certain amount of pioneer work to

be done, especially in South America, but the explorer of the future must be very differently equipped from the pioneer of the past. Something more is wanted now than a daring spirit and a geographical instinct. What we now want, even for pioneers, are men who have been thoroughly trained and who will be content to devote themselves to a limited region and work it out in all its details of features, and geological character and meteorology, and animals and plants; ever keeping in mind that man is the center of all, and that we only reach the last stage of the problem when we have worked out the action and reaction that is constantly taking place between man and his topographical surroundings. If in the solution of such problems as these there is as much activity shown in the next 50 years as there has been in the past half century in the work of pioneer exploration, there will not only be an unprecedentedly rich harvest for science, but also, I venture to think, magnificent results bearing on the social and individual welfare of man, who can not but benefit from a better knowledge of his geographical settings.

In the vast amount of the work of exploration during the half century, the British Empire, I think, may claim the lion's share.

> "We sailed wherever ship could sail,
> We founded many a mighty State,
> Pray God our greatness may not fall
> Through craven fear of being great."

I fear I have left little time to deal with the other two sections of the subject—the progress that has been made in raising the standard of geography as a department of scientific research, and the improvements that have been introduced into geographical education. Until about 30 years ago I fear geography was not treated seriously in either of these aspects. Long before that, in the early seventies, attempts were made by the Royal Geographical Society to induce the universities to recognize the subject in their curricula; but the society was politely flouted. The subject, we were assured, was beneath the dignity of university recognition, and was only suited for elementary schools. At this we need not be surprised when we examine the geographical literature of the period. It is true, that in certain of our great narratives of exploration—Franklin, Ross, Darwin, Bates, Wallace, Livingstone, and others—the scientific side of the subject was dealt with seriously, but the few works which existed on general geography were entirely descriptive; no attempt was made to show the relations which existed between the various distributions over the earth's surface and the interaction between these and the human beings who had to adapt themselves to the geographical conditions or modify them for the benefit of humanity.

In 1884 the Royal Geographical Society decided to make a thorough inquiry into the position of geography at home and abroad;

and with the results of this inquiry they again approached the universities, this time happily with success. Schools of geography were established at Oxford and Cambridge, and in time lectureships in the subject were instituted at the Universities of Edinburgh and Glasgow, London, Liverpool, Manchester, Birmingham, Reading, Sheffield, Aberystwyth. It was just before this that the Manchester Geographical Society was formed, and a week or two later the Royal Scottish Geographical Society, with branches in Glasgow, Dundee, and Aberdeen, followed at intervals by similar societies in Liverpool, Newcastle, Leeds, Southampton. Thus geography was raised to an altogether different platform in this country from the lowly position she had previously occupied, she was placed on a level with the subject in Germany, though that pushful country had the start of us by many years, as she has had in other directions, and a long leeway has to be covered. But we have been making headway. Apart from the purely educational work carried out by the universities, a beginning has been made in the work of geographical research. Both at Oxford and Cambridge, at the London School of Economics, and I believe at Edinburgh and Glasgow work of this kind is encouraged. On the university programs we have such heads as the principles of geography; survey of the natural regions of the globe; land forms and the morphology of the continents; meteorology, climatology, and oceanography; human geography in its various phases; geographical methods of notations, and so on. To the university tutor, the schoolmaster, the textbook compiler of 30 years ago, most of this would have been an unknown tongue. Examples of what may be regarded as geographical research work have been forthcoming from trained men like Mill, Mackinder, Chisholm, George Adam Smith, Herbertson, Grant Ogilvie, Roxby, Miss Newbigin, and others on this side, and by Davis, Huntington, Miss Semple, Brigham, and others in the States, which may be said to have been inspired from the mother country. Much good work has been done by the various students in the geographical distribution of vegetation in this country. As samples of scientific exploring work I might refer to Sir John Murray's investigations of the Scottish lochs; Mill's survey of a region in Sussex; Günther's researches on the Italian coast line; Hogarth, Ramsay, and others in the Near East; Willcocks in Mesopotamia; Filippi, Stein, Carruthers, and Huntington in central Asia; Hamilton Rice in South America; Scott, Shackleton, Bruce, and Mawson in the Antarctic. All this is a good beginning, and there is every reason to hope for still further work of this kind in the future, if those responsible for geography at our universities will do their duty.

You still find some scientific men in England who deny that geography is a science or can ever be a science, because for one thing it

is a graphy and not a logy. It is remarkable if geography is the one thing in the universe that can not be dealt with on scientific methods, producing a body of knowledge as systematically arranged as that included under geology, meteorology, astronomy, or engineering, and other sections of the British Association. Personally it does not irk me whether geography is admitted to be a science or not. It is a department of investigation which deals with a field untouched by any other department—the earth as the home of humanity. Like other departments of inquiry, it can collect its facts and draw its inferences on scientific methods, with results which in many cases could be cited in the geographical output of Germany, and happily, as I have stated in a few instances, in our own country—of the first importance toward the solution of problems intimately associated with human life and activity. To quote from the anniversary address, in 1892, of the late Sir Mountstuart Grant Duff, president of the Royal Geographical Society:

> Whether it is taught or not taught in schools and universities, geography must in the nature of things rule the territory in which the sciences relating to organic life, from history down to the structure of the humblest animate thing, meet the sciences which have to do with inorganic nature. Call it a graphy or a logy or a Kunde or what you please, it remains the body of knowledge which has to do with the theater of the activity of man and all things that have life. We may stunt and injure the activity of the next generation by refusing to teach it, but eventually it must obtain the position which the greatest of living systematic botanists, Hooker, claimed for it in 1886. "It must permeate," he said, "the whole of education to the termination of the university career, every subject taught having a geographical aspect."

With such authorities as these on our side we have no need to be ashamed of the work our science has performed in the past and is capable of performing in the future. In this country we are comparatively new to the work; only feeling our way, as it were; only trying to find out exactly what are the conditions under which our line of research will produce the best results, what are the limits within which we must work. It is true that geography is the mother of all the sciences, and though her numerous children have long ago set up for themselves, still she has more or less intimate relations with many of them. All the same, she must not be too grasping; she ought to form a clear idea of what she has a right to, what are the limits of her field of operations. To vary the simile, the geographers in this country have been moving into a much more spacious mansion; we have hardly had time to put our house in order; we may find when we do so that we have not room for all the furniture that some of our friends would like to squeeze into it. Anything like overcrowding is unnecessary and would be embarrassing. Ellsworth Huntington, one of the most active and most original of our younger geographers, * * * has the fullest belief in the influence of

geographical conditions on history and other human activities; but he maintains that the claims made in this respect are often too vague to convince the skeptical historian. What we want, he says, is a more precise statement as to the nature and amount, the quantity and quality, in each case of this environmental influence compared with various other elements. Probably we can never reach mathematical precision in this respect, as we might do in other departments of our subject; but it would be a splendid exercise in geographical research and in mental training for the qualified student of the subject to tackle the problem in certain specific instances. A group of physical features might be taken—say the Alps, or the Himalayas, or the deserts of central Asia, or the Sahara—and the question of their control over human distribution and human activity worked out with as much precision as possible. Or a particular country or region might be selected, and the control which geographical conditions have exercised on its history and development, as compared with other factors in the problem, be indicated.

As to the progress which has been made in geographical education outside the universities during the period, let anyone who is old enough recall the textbooks of 30 years ago, with their dreary list of names and little more—names of capes, names of bays, names of mountains, names of rivers, names of lakes, names of towns, all completely isolated, as if they had no sort of relation to each other nor to the human beings who had to live and move and have their being among them. We had such tags as Edinburgh, Leith, Portobello, Musselburgh, and Dalkeith, all on the Firth of Forth; London on the Thames; Colchester on the Colne, famous for its oysters; Peterborough on the Nen, near which is Fotheringay Castle, where Mary, Queen of Scots, was cruelly beheaded, and such like items. No wonder that geography was rejected and despised by the universities if this kind of thing was all it had to say for itself. Then there were the featureless atlases and wall maps, the value of which was estimated mainly by the number of names which they contained. Pictures, photographs, stereos, the lantern, were regarded as too childish to be used for serious educational or scientific purposes, while, as for the many other appliances now available for geographical education, no one seems to have thought them possible. Out-of-door work in those days was undreamed of.

Need I remind you of the change in all these directions which has taken place during the last 30 years? Contrast the conditions then and now. It might seem invidious if I referred to any particular textbooks or treatises or maps and other appliances. I am sure it is unnecessary before an audience like this. The ever-increasing series of treatises and textbooks which are being produced, and for which, therefore, there must be a demand, are no doubt familiar

to you all. Some may be open to criticism, but all, from the most bulky and elaborate down to the modest elementary textbook, are on a totally different plane from those of 30 years ago.

But textbooks and maps are not everything in geographical teaching, and, happily, in some of the universities and in a considerable number of secondary and even elementary schools outdoor work is carried on.

Geography, like geology, has to deal with a concrete earth, and not merely with maps. It has surface features of all kinds to investigate, and the life that is lived amid these features and is to a considerable extent conditioned by them. It is the duty of geography, as it is of geology, to investigate these conditions on the spot and to work out the problems suggested by them. This department of geological work is still in its infancy; a mere collection of local facts and statistics is not enough; correlations ought to be investigated and deductions as precise as possible made as to the results of the interaction of the various factors.

A new epoch in the history of geographical education in England may be said to have begun when the board of education issued its regulations for the teaching of geography in secondary schools. Perhaps the most important point in the new regulations was that a definite number of hours a week—not less than two periods of school work and one of home work—were to be allotted to geography in secondary schools. Provision had to be made for a four-year course of the work, and the course had to include the geography of the whole world, so that the custom of keeping the pupil at work on one or two particular continents, according to exigencies of examinations, until he left school was discountenanced. Particular attention was given in the board's circular to the importance of practical exercises, such as "worked-out problems, together with original maps and plans," in geographical instruction. Consequence had to be connected with cause and reasons had to be stated with facts, instead of presenting lists of place names, rivers, communications, and so on, as catalogues to be learned without being understood.

When the board's regulations were issued, teachers who had specialized in geography were few, and the regulations would have been a long time coming into practical effect if suitable manuals had not been forthcoming. The board defined the spirit of the teaching it desired to establish, and gave the outlines of a scheme, but it left the actual working out to the teachers themselves, and in most cases they had to obtain their guidance from manuals and text-books. Much had already been done by the university extension lectures to teachers. The teaching of the subject throughout the country now underwent a change on account of the new condition. From being classed as memory work, which could be put into the hands of any

teacher, geography became a reasoning subject requiring individual work by the students and sound knowledge by the teacher as much as any other subject taught on scientific principles. Too much attention was perhaps paid at the outset to the working of practical problems and exercises, but this has now righted itself, and the human note is not forgotten while the scientific method of arriving at it is followed. What is more important than anything else is that the standard of work in geography is steadily rising. The subject is being treated more and more on a regional basis, and the work is consequently gaining in intelligence.

The program for instruction for elementary schools has been greatly improved on the best lines, and where teachers have been adequately trained to deal with it intelligently the results are a great advance on what passed for geography 30 years ago. But in the case of the younger pupils, I fear it is difficult to get them to do little more than to read narratives. In the upper classes of these schools, however, more systematic work is prescribed in the official program, and I believe the whole tendency is toward an improvement upon the methods and outlook of previous years. The inspectors of the board of education consider that geography is now on a much better footing than it was, and is often intelligently taught. Much depends upon the training which students in training colleges receive before they are turned out to carry on the work of education.

In certain institutions facilities are provided for training college students going through a course of instruction in geography, with opportunities of actual practice in schools. I am not sure that this method is quite satisfactory; it would be well if all training colleges were as fully equipped for geographical work as they are in other departments. In no class of school can geography be satisfactorily taught on modern lines unless the teachers are as seriously trained in that as they are in grammar, arithmetic, or any other essential parts of their course. In certain training colleges the subject is in charge of geographical specialists. This ought to be the case in all training colleges, as well as in the universities from which the supply of teachers for secondary and higher schools are drawn. But if the progress is as marked in the next quarter of a century as it has been in the past, there can be little doubt that the existing deficiencies will be removed, and geographical education will be on as satisfactory a footing in Britain as it is in Germany.

But time forbids me to go further. I hope I have succeeded in showing that during the last 30 years geography has grown in stature and in strength in this country; that, in fact, it has reached man's estate, and that both in education and in research it is trying to do a man's work. It has still much to learn that can only come by

experience, but it is bound to come if we work in the future as in the past, and that all the more rapidly and successfully in proportion to the increasing number of workers. The Royal Geographical Society has itself extended, not only in numbers, but in varied activities, during these years. Its staff has been quadrupled, to keep pace with its work; the scientific side of the subject receives more and more attention. The efforts of the parent society are effectually supported by those younger societies which have grown up in various great centers. It is often stated that the work of geographical societies is nearly completed; that they will soon have had their day and cease to be, for the world is being rapidly explored and mapped. There is plenty of work still to do in exploration and mapping, and when that is complete the real work of geography and geographical societies will only begin. The explorer and map maker only lay down the foundations of the subject; it will remain for generations of geographers to rear thereon a stately structure fitly representing "the kingdoms of this world, and the glory of them."

THE RELATION OF PURE SCIENCE TO INDUSTRIAL RESEARCH.[1]

By J. J. Carty.

It is not strange that many years ago Huxley, with his remarkable precision of thought and his admirable command of language, should have indicated his dissatisfaction with the terms "pure science" and "applied science," pointing out at the same time that what people call "applied science" is nothing but the application of pure science to particular classes of problems. The terms are still employed, possibly because, after all, they may be the best ones to use, or perhaps our ideas, to which these expressions are supposed to conform, have not yet become sufficiently definite to have called forth the right words.

It is not the purpose of this address, however, to suggest better words or expressions, but rather to direct attention to certain important relations between purely scientific research and industrial scientific research which are not yet sufficiently understood.

Because of the stupendous upheaval of the European war with its startling agencies of destruction—the product of both science and the industries—and because of the deplorable unpreparedness of our own country to defend itself against attack, there has begun a great awakening of our people. By bringing to their minds the brilliant achievements of the membership of this institute in electric lighting and power and communications and by calling their attention to the manifold achievements of the members of our sister societies in mechanical and mining and civil engineering, and the accomplishments of our fellow workers, the industrial chemists, they are being aroused to the vital importance of the products of science in the national defense.

Arising out of this agitation comes a growing appreciation of the importance of industrial scientific research, not only as an aid to military defense but as an essential part of every industry in time of peace.

[1] President's address at the Thirty-Third Annual Convention of the American Institute of Electrical Engineers, Cleveland, Ohio, June 27, 1916. Copyright, 1916, by American Institute of Electrical Engineers. Reprinted by permission.

Industrial research, conducted in accordance with the principles of science, is no new thing in America. The department which is under my charge, founded nearly 40 years ago to develop, with the aid of scientific men, the telephone art, has grown from small beginnings with but a few workers to a great institution employing hundreds of scientists and engineers, and it is generally acknowledged that it is largely owing to the industrial research thus conducted that the telephone achievements and development in America have so greatly exceeded those of other countries.

With the development of electric lighting and electric power and electric traction, which came after the invention of the telephone, industrial scientific research laboratories were founded by some of the larger electrical manufacturing concerns, and these have attained a world-wide reputation. While vast sums are spent annually upon industrial research in these laboratories, I can say with authority that they return to the industries each year improvements in the art which, taken all together, have a value many time greater than the total cost of their production. Money expended in properly directed industrial research, conducted on scientific principles, is sure to bring to the industries a most generous return.

While many concerns in America now have well-organized industrial research laboratories, particularly those engaged in metallurgy and dependent upon chemical processes, the manufacturers of our country as a whole have not yet learned of the benefits of industrial scientific research and how to avail themselves of it.

I consider that it is the high duty of our institute and of every member composing it, and that a similar duty rests upon all other engineering and scientific bodies in America, to impress upon the manufacturers of the United States the wonderful possibilities of economies in their processes and improvements in their products which are opened up by the discoveries in science. The way to realize these possibilities is through the medium of industrial research conducted in accordance with scientific principles. Once it is made clear to our manufacturers that industrial research pays they will be sure to call to their aid men of scientific training to investigate their technical problems and to improve their processes. Those who are the first to avail themselves of the benefits of industrial research will obtain such a lead over their competitors that we may look forward to the time when the advantages of industrial research will be recognized by all.

Industrial scientific research departments can reach their highest development in those concerns doing the largest amount of business. While instances are not wanting where the large growth of the institution is the direct result of the care which is bestowed upon industrial research at a time when it was but a small concern, nevertheless

conditions to-day are such that without cooperation among themselves the small concerns can not have the full benefits of industrial research, for no one among them is sufficiently strong to maintain the necessary staff and laboratories. Once the vital importance of this subject is appreciated by the small manufacturers many solutions of the problem will promptly appear. One of these is for the manufacturer to take his problem to one of the industrial research laboratories already established for the purpose of serving those who can not afford a laboratory of their own. Other manufacturers doing the same, the financial encouragement received would enable the laboratories to extend and improve their facilities so that each of the small manufacturers who patronizes them would in course of time have the benefit of an institution similar to those maintained by our largest industrial concerns.

Thus, in accordance with the law of supply and demand, the small manufacturer may obtain the benefits of industrial research in the highest degree, and the burden upon each manufacturer would be only in accordance with the use he made of it, and the entire cost of the laboratories would thus be borne by the industries as a whole, where the charge properly belongs. Many other projects are now being considered for the establishment of industrial research laboratories for those concerns which can not afford laboratories of their own, and in some of these cases the possible relation of these laboratories to our technical and engineering schools is being earnestly studied.

Until the manufacturers themselves are aroused to the necessity of action in the matter of industrial research there is no plan which can be devised that will result in the general establishment of research laboratories for the industries. But once their need is felt and their value appreciated and the demand for research facilities is put forth by the manufacturers themselves, research laboratories will spring up in all our great centers of industrial activity. Their number and character and size and their method of operation and their relation to the technical and engineering schools and the method of their working with the different industries are all matters which involve many interesting problems—problems which I am sure will be solved as they present themselves and when their nature has been clearly apprehended.

In the present state of the world's development there is nothing which can do more to advance American industries than the adoption by our manufacturers generally of industrial research conducted on scientific principles. I am sure that if they can be made to appreciate the force of this statement, our manufacturers will rise to the occasion with all that energy and enterprise so characteristic of America.

So much has already been said and so much remains to be said urging upon us the importance of scientific research conducted for the sake of utility and for increasing the convenience and comfort of mankind that there is danger of losing sight of another form of research which has for its primary object none of these things. I refer to pure scientific research.

In the minds of many there is confusion between industrial scientific research and this purely scientific research, particularly as the industrial research involves the use of advanced scientific methods and calls for the highest degree of scientific attainment. The confusion is worse because the same scientific principles and methods of investigation are frequently employed in each case and even the subject matter under investigation may sometimes be identical.

The misunderstanding arises from considering only the subject matter of the two classes of research. The distinction is to be found not in the subject matter of the research, but in the motive.

The electrical engineer, let us say, finding a new and unexplained difficulty in the working of electric lamps, subjects the phenomenon observed to a process of inquiry employing scientific methods, with a view to removing from the lamps an objectionable characteristic. The pure scientist at the same time investigates in precisely the same manner the same phenomenon, but with the purpose of obtaining an explanation of a physical occurrence, the nature of which can not be explained by known facts. Although these two researches are conducted in exactly the same manner, the one nevertheless comes under the head of industrial research and the other belongs to the domain of pure science. In the last analysis the distinction between pure scientific research and industrial scientific research is one of motive. Industrial research is always conducted with the purpose of accomplishing some utilitarian end. Pure scientific research is conducted with a philosophic purpose, for the discovery of truth, and for the advancement of the boundaries of human knowledge.

The investigator in pure science may be likened to the explorer who discovers new continents or islands or hitherto unknown territory. He is continually seeking to extend the boundaries of knowledge.

The investigator in industrial research may be compared to the pioneers who survey the newly discovered territory in the endeavor to locate its mineral resources, determine the extent of its forests, and the location of its arable land, and who in other ways precede the settlers and prepare for their occupation of the new country.

The work of the pure scientists is conducted without any utilitarian motive, for, as Huxley says, "that which stirs their pulses is the love of knowledge and the joy of discovery of the causes of things sung by the old poet—the supreme delight of extending the

realm of law and order ever further toward the unattainable goals of the infinitely great and infinitely small, between which our little race of life is run." While a single discovery in pure science when considered with reference to any particular branch of industry may not appear to be of appreciable benefit, yet when interpreted by the industrial scientist, with whom I class the engineer and the industrial chemist, and when adapted to practical uses by them, the contributions of pure science as a whole become of incalculable value to all the industries.

I do not say this because a new incentive is necessary for the pure scientist, for in him there must be some of the divine spark and for him there is no higher motive than the search for the truth itself. But surely this motive must be intensified by the knowledge that when the search is rewarded there is sure to be found, sooner or later, in the truth which has been discovered, the seeds of future great inventions which will increase the comfort and convenience and alleviate the sufferings of mankind.

By all who study the subject, it will be found that while the discoveries of the pure scientist are of the greatest importance to the higher interests of mankind, their practical benefits, though certain, are usually indirect, intangible, or remote. Pure scientific research unlike industrial scientific research can not support itself by direct pecuniary returns from its discoveries.

The practical benefits which may be immediately and directly traced to industrial research, when it is properly conducted, are so great that when their importance is more generally recognized industrial research will not lack the most generous encouragement and support. Indeed, unless industrial research abundantly supports itself it will have failed of its purpose.

But who is to support the researches of the pure scientist, and who is to furnish him with encouragement and assistance to pursue his self-sacrificing and arduous quest for that truth which is certain as time goes on to bring in its train so many blessings to mankind? Who is to furnish the laboratories, the funds for apparatus and for traveling and for foreign study?

Because of the extraordinary practical results which have been attained by scientifically trained men working in the industrial laboratories and because of the limited and narrow conditions under which many scientific investigators have sometimes been compelled to work in universities, it has been suggested that perhaps the theater of scientific research might be shifted from the university to the great industrial laboratories which have already grown up or to the even greater ones which the future is bound to bring forth. But we can dismiss this suggestion as being unworthy.

Organizations and institutions of many kinds are engaged in pure scientific research, and they should receive every encouragement, but the natural home of pure science and of pure scientific research is to be found in the university, from which it can not pass. It is a high function of the universities to make advances in science, to test new scientific discoveries, and to place their stamp of truth upon those which are found to be pure. In this way only can they determine what shall be taught as scientific truth to those who, relying upon their authority, come to them for knowledge and believe what they teach.

Instead of abdicating in their favor, may not our universities, stimulated by the wonderful achievements of these industrial laboratories, find a way to advance the conduct of their own pure scientific research, the grand responsibility for which rests upon them? This responsibility should now be felt more heavily than ever by our American universities, not only because the tragedy of the great war has caused the destruction of European institutions of learning, but because even a worse thing has happened. So great have been the fatalities of the war that the universities of the Old World hardly dare to count their dead.

But what can the American universities do, for they, like the pure scientists, are not engaged in a lucrative occupation? Universities are not money-making institutions, and what can be done without money?

There is much that can be done without money. The most important and most fundamental factor in scientific research is the mind of a man suitably endowed by nature. Unless the scientific investigator has the proper genius for his work, no amount of financial assistance, no apparatus or laboratories, however complete, and no foreign travel and study, however extensive, will enable such a mind to discover new truths or to inspire others to do so. Judgment and appreciation and insight into character on the part of the responsible university authorities must be applied to the problem, so that when the man with the required mental attributes does appear he may be appreciated as early in his career as possible. This is a very difficult thing to do indeed. Anyone can recognize such a man after his great achievements have become known to all the world, but I sometimes think that one who can select early a man who has within him the making of the scientific discoverer must have been himself fired with a little of the divine spark. Such surely was the case with Sir Humphrey Davy, himself a great discoverer, who, realizing the fundamental importance of the man in scientific discovery, once said that Michael Faraday, whose genius he was prompt to recognize, constituted his greatest discovery.

I can furnish no formula for the identification of budding genius and I have no ready-made plan to lay before the universities for the advancement of pure scientific research. But as a representative of engineering and industrial research, having testified to the great value of pure scientific research, I venture to suggest that the university authorities themselves might well consider the immense debt which engineering and the industries and transportation and communications and commerce owe to pure science, and to express the hope that the importance of pure scientific research will be more fully appreciated both within the university and without, for then will come—and then only—that sympathetic appreciation and generous financial support so much needed for the advancement of pure scientific research in America.

While there are many things, and most important things, which the universities can do to aid pure science without the employment of large sums of money, there are nevertheless a great many things required in the conduct of pure scientific research which can be done only with the aid of money. The first of these, I think, is this:

When a master scientist does appear and has made himself known by his discoveries, then he should be provided with all of the resources and facilities and assistants that he can effectively employ, so that the range of his genius will in no way be restricted for the want of anything which money can provide.

Every reasonable and even generous provision should be made for all workers in pure science, even though their reputations have not yet become great by their discoveries, for it should be remembered that the road to great discoveries is long and discouraging and that for one great achievement in science we must expect numberless failures.

I would not restrict these workers in pure science to our great universities, for I believe that they should be located also at our technical schools, even at those with the most practical aims. In such schools the influence of a discoverer in science would serve as a balance to the practical curriculum and familiarize the student with the high ideals of the pure scientist and with his rigorous methods of investigation. Furthermore, the time has come when our technical schools must supply, in largely increasing numbers, men thoroughly grounded in the scientific method of investigation for the work of industrial research.

Even the engineering student, who has no thoughts of industrial research, will profit by his association with the work of the pure scientist, for if he expects ever to tread the higher walks of the engineering profession he must be qualified to investigate new problems in engineering and devise methods for their solution and for such

work a knowledge of the logical processes of the pure scientist and his rigorous methods of analyzing and weighing evidence in his scrupulous search for the truth will be of the greatest value.

Furthermore, the engineering student should be taught to appreciate the ultimate great practical importance of the results of pure scientific investigation and to realize that pure science furnishes to engineering the raw material, so to speak, which he must work into useful forms. He should be taught that after graduation it will be most helpful to him and even necessary, if he is to be a leader, to watch with care the work of the pure scientist and to scrutinize the reports of new scientific discoveries to see what they may contain that can be applied to useful purposes and more particularly to problems of his own which require solution. There are many unsolved problems in applied science to-day which are insoluble in the present state of our knowledge, but I am sure that in the future, as has so often happened in the past, these problems will find a ready solution in the light of pure scientific discoveries yet to be made. When thus regarded the work of the pure scientist should be followed with most intense interest by all of those engaged in the application of science to industrial purposes. Acquaintance, therefore, with the pure scientist, with his methods and results, is of great importance to the student of applied science. I believe that there is need of a better understanding of the relations between the pure scientist and the applied scientist and that this understanding would be greatly helped by a closer association between the pure scientist and the students in the technical schools.

While I have drawn a valid distinction between the work of the two, they nevertheless have much in common. Both are concerned with the truth of things, one to discover new truths and the other to apply these truths to the uses of man. While the object of the engineer is to produce from scientific discoveries useful results, these results are for the benefit of others. They are dedicated to the use of mankind and, as is the case with the pure scientist, they should not be confused with the pecuniary compensation which the engineer himself may receive for his work, for this compensation is slight, often infinitesimally so, compared with the great benefits received by others. Like the worker in pure science, the engineer finds inspiration in the desire for achievement and his real reward is found in the knowledge of the benefits which others receive from his work.

There are many other things which might be discussed concerning the conduct of pure scientific research in our universities and technical schools, but enough has been said to make it plain that I believe such work should be greatly extended in all of our American universities and technical institutions. But where are the universities to obtain the money necessary for the carrying out of a

grand scheme of scientific research? It should come from those generous and public spirited men and women who desire to dispose of their wealth in a manner well calculated to advance the welfare of mankind, and it should come from the industries themselves, which owe such a heavy debt to science. While it can not be shown that the contribution of any one manufacturer or corporation to a particular purely scientific research will bring any return to the contributor or to others, it is certain that contributions by the manufacturers in general and by the industrial corporations to pure scientific research as a whole will in the long run bring manifold returns through the medium of industrial research conducted in the rich and virgin territory discovered by the scientific explorer.

It was Michael Faraday, one of the greatest of the workers in pure science, who in the last century discovered the principle of the dynamo electric machine. Without a knowledge of this principle discovered by Faraday the whole art of electrical engineering as we know it to-day could not exist and civilization would have been deprived of those inestimable benefits which have resulted from the work of the members of this institute.

Not only Faraday in England, but Joseph Henry in our own country and scores of other workers in pure science have laid the foundations upon which the electrical engineer has reared such a magnificent structure.

What is true of the electrical art is also true of all of the other arts and applied sciences. They are all based upon fundamental discoveries made by workers in pure science, who were seeking only to discover the laws of nature and extend the realm of human knowledge.

By every means in our power, therefore, let us show our appreciation of pure science, and let us forward the work of the pure scientists, for they are the advance guard of civilization. They point the way which we must follow. Let us arouse the people of our country to the wonderful possibilities of scientific discovery and to the responsibility to support it which rests upon them, and I am sure that they will respond generously and effectively. Then I am confident that in the future the members of this institute, together with their colleagues in all of the other branches of engineering and applied science, as well as the physician and surgeon, by utilizing the discoveries of pure science yet to be made, will develop without number marvelous new agencies for the comfort and convenience of man, and for the alleviation of human suffering. These, gentlemen, are some of the considerations which have led me here in my presidential address to urge upon you the importance of a proper understanding of the relations between pure science and industrial research.

MINE SAFETY DEVICES DEVELOPED BY THE UNITED STATES BUREAU OF MINES.

By Van. H. Manning, *Director.*

[With 7 plates.]

The present article outlines the character and the method of use of some of the more important devices developed by the Bureau of Mines in its investigations looking to greater safety in mining, and discusses the bureau's work in educating and training miners to protect themselves from harm and in furthering the use of safer explosives and equipment in mines. Although the Bureau of Mines is investigating conditions, methods, and equipment in the quarrying, metallurgical, and other mineral industries as well as in mining, this article deals particularly with appliances used in coal mining.

MINE RESCUE AND FIRST-AID WORK OF THE BUREAU OF MINES.

In its mine safety and first-aid work the Bureau of Mines has four main objectives, as follows:

First. To investigate and report on mine accidents to the end that their causes may be more thoroughly understood and the mine operators advised as to the best means of avoiding them.

Second. To teach the use of oxygen mine-rescue apparatus and the methods of performing first aid to the injured.

Third. To send trained rescue crews to the scenes of explosions, fires, or other accidents in order to save life and property.

Fourth. To acquaint mining men with safe and unsafe mining practices through lectures, conferences, motion pictures, and the wide but judicious distribution of its publications.

During the fiscal year 1916, 89 accidents were investigated and a thorough report made on each. If a given report indicated that electricity had been a contributory cause of the accident the matter was referred to the bureau's electrical engineers for consideration and recommendations as to ways of preventing similar accidents. Similarly problems concerning explosives, mine gases, and the coal dust and other hazards are referred to the bureau's experts.

It is, of course, well understood that mining is a hazardous occupation and that injuries more or less severe are of daily occurrence in large mines. From the very nature of the work, practically all

men injured underground have to be transported a considerable distance before a doctor sees them, and frequently one to two hours may elapse between the time of injury and the time when the doctor first sees the patient. Consequently it is highly desirable that each miner should understand proper first-aid methods.

Stationed at various mining centers throughout the country the bureau has first-aid miners, men with wide mining and first-aid experience, who have been instructed in standardized first-aid methods by the bureau's mine surgeon. These men either work from the bureau headquarters in their district or are attached to the bureau's mine rescue cars or automobile rescue trucks, on which they travel from town to town, giving without charge a complete course in first aid. The bureau maintains eight such cars and three automobile rescue trucks. The miner is taught how to give artificial respiration, treat shock, control hemorrhage, and bandage any part of the body for fracture, dislocation, wound, or burn, and is shown the best method of transporting an injured person.

Mine rescue methods have been taught in conjunction with the first-aid training. Bureau employees, designated foreman miners, accompany its rescue cars and trucks and teach the miners how to use the principal types of self-contained oxygen rescue apparatus. This apparatus consists of a steel cylinder containing oxygen at a pressure of approximately 2,000 pounds per square inch, with a reducing valve which allows the flow of a definite quantity of oxygen per minute, at a pressure slightly above atmospheric, to pass from the cylinder to a reservoir from which it is breathed by the wearer. The exhaled air flows to a compartment containing regenerating material, usually sodium hydroxide, by which the carbon dioxide of the exhaled air is removed. The regenerated air joins the stream of oxygen from the reducing valve, and the cycle is repeated.

The foreman miners of the bureau give instruction in recovery methods, laying especial emphasis on the use of none but fully manned crews and on the need of the crews having such adjuncts as safety lamps, canary birds (for detecting poisonous gases), life lines, and telephones. It is gratifying to note that but few lives have been lost in the past year through heroic but misdirected and unorganized recovery work. Before the organization of the bureau the loss of lives from this cause was high.

Experiments looking toward a more thorough understanding of rescue apparatus and resuscitators have been carried on at the bureau's Pittsburgh experiment station. Owing to the European war, apparatus formerly made in Germany and England are now made in this country, and it has been necessary to thoroughly inspect and test this American-made material. As a result of these tests

some serious defects were pointed out and these have been remedied by the manufacturers. A new and improved type of apparatus, subsequently described, has been developed by the bureau.

In their training work the bureau's field men observe many instances of safe and unsafe practice, and the knowledge thus gained they utilize through their district in conferences with the miners and the operators. When it is felt that one or more of the bureau's publications will be helpful to a particular miner or operator, the publications are forwarded. When the bureau's field men find gaseous or dusty conditions in mines and these conditions are dangerous or not well understood, they take samples of the air or dust and forward these to the bureau's laboratory for analysis. The information obtained is then available for the operator concerned.

The operators of mines in which adequate consideration is given to safety features are being given reduced rates for workmen's compensation insurance. The benefits to the miners are even greater in that accidental deaths and injuries are being materially reduced.

USE OF MOTION PICTURES IN MINE SAFETY WORK.

In its general mine safety work the Bureau of Mines makes effective use of motion pictures to illustrate (1) safe and unsafe methods and practices and (2) Bureau of Mines standard methods of mine rescue and first aid.

Most of these films are taken by bureau photographers in cooperation with various mining companies; some are purchased, and others are presented to the bureau. They are shown to the mining public by bureau representatives on every possible occasion, largely in connection with mine-rescue and first-aid training. A chronological loan record is kept of past, present, and prospective loans of films. It is estimated that during the past fiscal year films were shown to 160,000 mining people, not including the thousands of visitors to the Government safety-first train.

As these films are for a specific vital educational purpose—to instruct mine workers, many of whom know little of the English language or the work in which they are engaged—the scenarios are, so far as possible, criticized by expert engineers and surgeons.

Stationary photographs, taken with the same educational object, are used to illustrate bureau reports and for lantern slides. That they may be intelligible to non-English-speaking miners, the titles to many of these slides are in four languages.

When the interest of the miners in rescue, first-aid, and general safety work can not otherwise be aroused, a lecture by bureau engineers, with motion pictures or lantern slides of safe practices as contrasted with dangerous practices, enables the lecturer to organize first-

aid and rescue classes, thus starting a safety propaganda where it otherwise would not be received.

NEW FORM OF OXYGEN MINE RESCUE APPARATUS.

After a long period of experiment the Bureau of Mines has developed a new form of oxygen breathing apparatus for use in poisonous or irrespirable atmospheres in mines after fires or explosions. It is called the Gibbs apparatus, after its chief designer, W. E. Gibbs, engineer of mine-safety investigations, of the bureau.

In such apparatus, as it is impracticable to compress into a portable tank enough air to supply the breathing needs of the wearer for the hour or two during which he remains in poisonous atmospheres, pure oxygen is used. In general, an oxygen rescue apparatus consists of a small tank of compressed oxygen, a reducing valve through which the oxygen flows to a mouthpiece connected to the breathing bag by flexible tubes, and a receptacle containing caustic soda for absorbing the carbon dioxide from the exhaled air. Valves that open and close at each breath prevent expired air from returning to the lungs before it has passed through the purifier.

To construct an apparatus of this kind would be relatively simple if it were not for the conditions under which the apparatus is worn. As rescue crews work in the unmapped wreckage following mine accidents, in a presumably irrespirable atmosphere and often in smoke so dense that their electric lamps are of small help, any failure of an oxygen rescue apparatus may mean death to the wearer. Moreover, the labor of exploration and rescue is often arduous, and the apparatus worn must be as light as is consistent with strength and yet strong enough to withstand the hard knocks it is sure to receive. It must be mechanically so perfect that it will not fail to function, and yet be so simple that it can be manipulated with safety in the dark and in surroundings that exhaust the wearer both physically and mentally.

The Gibbs apparatus, developed by the Bureau of Mines, differs from others in the following particulars:

By means of a new form of reducing valve the oxygen is supplied to the user at a variable rate which constantly adjusts itself to his immediate demands.

A new form of carbon dioxide absorber keeps the inspired air pure and prevents it from reaching an uncomfortably high temperature during the two-hour standard period of use.

The pressure gauge, which indicates the available supply of oxygen, is read by touch. Thirty minutes before the supply is exhausted it rings an alarm.

The apparatus, a self-contained unit, is carried wholly on the back of the wearer, so that his arms are unimpeded by the customary front breathing bag and its connections.

An aluminum cover incloses the whole apparatus and protects it from injury.

A pump within the mouthpiece permits the removal of saliva as fast as it is formed.

The weight of the apparatus is only 30 pounds. Its general appearance is shown in plate 1.

The apparatus has satisfactorily passed severe tests. In use it is expected to prove more satisfactory than any such device hitherto available. Consequently, the United States will be independent of foreign makers of breathing apparatus for its future supply.

DEVELOPMENT OF PERMISSIBLE COAL-MINE EXPLOSIVES.

CHARACTER AND INCREASED USE OF PERMISSIBLE EXPLOSIVES.

The risks arising in the handling, transportation, and use of explosives have been lessened by the introduction of improved explosives for coal mines. In the past black powder was generally used in mines that were gaseous or contained dry coal dust, and many great mine disasters resulted. The Bureau of Mines seeks to have safer explosives used in dangerous mines, and to this end is testing explosives to determine their permissibility for such use. Those passing the tests are termed permissible explosives, and their use is urged in all mines containing gas and large quantities of bituminous coal dust. In the year 1908 only 2,000,000 pounds of these permissible explosives was used in such mines, whereas in 1915 the amount of permissible explosives had grown to nearly 22,000,000 pounds.

On October 1, 1916, 148 explosives had passed the required tests and had been placed on the Bureau of Mines list of permissible explosives.

MISCELLANEOUS TESTS OF PERMISSIBLE EXPLOSIVES.

Other tests to which permissible explosives are subjected are as follows:

Samples of the explosives on the permissible list are frequently collected for a chemical examination to determine whether they are similar in all respects to the samples originally tested by the bureau.

The products of combustion of explosives submitted for permissibility are examined for poisonous gases, and no explosive is admitted to the permissible list which gives more than 158 liters (5.5 cubic feet) of poisonous gases from 1½ pounds of explosive.

All explosives are examined for liability of the ingredients to exude from the containers.

The relative strength of detonators is determined by the sand test as perfected by the bureau.

TESTS OF DETONATORS AND ELECTRIC DETONATORS.

The Bureau of Mines not only tests explosives to determine their permissibility, but also prescribes the conditions under which they are to be used. One of these conditions is that permissible explosives shall be fired by a detonator, preferably an electric detonator, having a charge equivalent to that of the standard detonator used at the bureau's Pittsburgh experiment station. The grade of electric detonator is recommended by the manufacturer for use with a particular brand of permissible explosive; and should the explosive pass the required tests with the grade recommended, the same grade is prescribed by the bureau, but in no case can it be of less efficiency than a No. 6 electric detonator. A further requirement is that the charge of the detonator or electric detonator shall consist by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate or their equivalents.

The importance of these prescribed conditions may be realized by considering the means whereby permissible explosives are fired in practice. Detonators or electric detonators are required for firing all permissible explosives now on the bureau's list. Although the explosives might, in many cases, be partly exploded by the aid of squibs or fuse or by means of black-powder primers, yet the explosion so produced would not be complete; the explosives would not be used to their best advantage, and the gases produced would usually be dangerous. Therefore it is safer to fire detonating explosives with detonators or electric detonators strong enough to cause complete detonation.

The results of experiments made by the bureau show that the average percentage of explosives failing to detonate was increased more than 20 per cent when the lower grades of electric detonators were used instead of No. 6 electric detonators and was increased more than 50 per cent when these lower grades were used instead of No. 8 electric detonators.

DEVELOPMENT OF SAFER MINE ELECTRICAL EQUIPMENT.

For several years past the bureau has been working to bring about the retirement from mines of dangerous open-flame lamps and the substitution of the relatively safe electric lamp operated by a battery carried on the miner's belt.

The individual electric lamp, if generally adopted, will be a long step toward safety, as it cannot start fires or explosions as open-flame lamps may. Moreover, electric lamps give more light and distribute

1. FRONT VIEW.

2. BACK VIEW, WITH ALUMINUM PROTECTIVE COVERING REMOVED.

GIBBS OXYGEN MINE RESCUE APPARATUS.

1. TROUGH BARRIER IN PLACE IN A MINE ENTRY.

2. CONCENTRATED BARRIER AFTER A LIGHT, SLOW-MOVING EXPLOSION.

the light better than flame safety lamps, and thus the miner obtains the added safety attendant upon good illumination.

The bureau's method of procedure is to examine and test lamps submitted to it and to issue approval labels to such lamps as meet the requirements prescribed by the bureau as a minimum standard. Seven types of electric lamps have thus been approved.

When the work was first undertaken there were few portable electric lamps in use in mines and these were not entirely satisfactory. At the present time there are between 75,000 and 100,000 portable electric lamps in use in the mines of this country, and the lamps approved by the bureau are being adopted at an average rate of about 2,000 per week.

Several years ago the bureau approved the first explosion-proof electric motor. These motors are designed to prevent any explosion or flash within the motor casing from igniting gas in the mine air surrounding the motor. The type of motor brought out by the bureau's approval was not only permissible for use in gaseous mines, but represented a standard of construction considerably superior to anything previously in use. One other motor has recently received the bureau's approval. These motors have met with considerable favor and at the present time are being adopted at the rate of about 1,000 a year. The bureau has applications for the test of 16 other machines, the development of which is being carried on by the manufacturers as rapidly as the present congested condition of their factories will permit.

For the past two years engineers of the bureau have been developing a set of suggested safety rules for the installation and use of electrical equipment in bituminous coal mines. These rules which are now in course of publication, were developed in cooperation with outside mining engineers and mine operators, and are the result of many conferences and revisions. No practical requirement has been omitted that will make safer the installation and use of electricity in mines, and it is therefore believed that the adoption of the rules will greatly further the cause of safety.

The approval system of the bureau is to be extended to the mechanical equipment of mines when the laboratory facilities now being provided are completed.

GASOLINE LOCOMOTIVES FOR MINES.

To determine the conditions under which gasoline locomotives might be used in mines without detriment to the health of miners an investigation was made of the maximum amount of carbon monoxide which may be produced by gasoline engines. This maximum amount determines the desirable size and the manner of use of such locomotives in a mine and the amount of ventilation necessary.

PREVENTION OF MINE EXPLOSIONS.

For the past six years experimental explosion tests have been conducted at the experimental mine of the Bureau of Mines near Bruceton, Pa., in connection with the investigation of coal-mine explosions and their prevention. As a result of these tests two recommendations are now being strongly made by the Bureau of Mines in connection with the prevention of mine explosions—first, that under conditions prevailing in the majority of the mines of the United States rock dust be used for rendering mine road dust noninflammable and, second, that rock-dust barriers be used at various points in the mine for limiting any explosions that may occur.

USE OF ROCK DUST TO PREVENT COAL-MINE EXPLOSIONS.

Another method of rendering coal dust inert is by watering, but unless the water is frequently applied it often happens that for considerable periods the road dust of mines using this method is not in satisfactory condition, because the water rapidly evaporates and leaves the dust dry; consequently the rock-dust method is strongly advocated, inasmuch as rock dust will give protection for much longer periods of time than will the application of water.

In the use of the rock-dust method the coal dust is removed from the mine roads as completely as possible and all the surfaces throughout the mine are then coated with dry pulverized rock dust. As the road dust will be gradually coated with an accumulation of coal dust it is desirable when the percentage of combustible dust reaches a certain figure that more rock dust be distributed. This is usually done by a so-called "rock-dusting machine."

In the event of an explosion the pressure wave that travels ahead of the explosion raises the road dust in a cloud and if this cloud is largely composed of incombustible material it tends to blanket the flame of the explosion and limit its travel. The rock-dust method has been tried in one mine in Colorado for a period of about five years and in three mines in Pennsylvania for periods of one to two years. It is believed that the method will be extensively used in the future.

ROCK-DUST BARRIERS.

A rock-dust barrier consists of a number of boxes or shelves filled with rock dust, which in the event of an explosion is automatically dumped, resulting in the formation of a thick cloud of rock dust and the blanketing of the flame. The plan of using the barriers is to place them at the entrances of panels or sections of the mine, so that if an explosion occurs in a panel or section so protected, it can not travel beyond, or if the explosion occurs in another part of the

TROUGH BARRIER.

1. CLOUD OF DUST CAUSED BY THE DISCHARGE OF ONE OF THE TROUGHS OF A TROUGH BARRIER IN A MINE ENTRY.

2. SAME CLOUD FROM A DIFFERENT POINT OF VIEW.

mine it can not travel into a protected panel or section. The use of the barriers should be supplementary to rock dusting or to the watering method of rendering the coal dust inert. If the watering or rock-dusting method fails and an explosion is propagated beyond its origin, then the barriers should be effective in limiting the explosion to the particular section of the mine in which it originates.

The original barrier, invented by J. Taffanel, of France, consisted of 10 to 15 shelves placed across the entry just beneath the roof, spaced about 10 feet apart, and loaded with rock dust. This barrier had two disadvantages: (1) If the explosion was light and slow moving it might pass under the barrier without discharging enough dust to quench the flame; and (2) the dust was exposed to the mine atmosphere, and under some conditions would become wet and packed, so that it was no longer in condition to be efficient in case of an explosion. Accordingly, a number of different types of rock-dust barriers were invented by George S. Rice, chief mining engineer of the Bureau of Mines, which did not have these disadvantages. All of these barriers are operated by the explosion itself through a leverage system sensitive to low pressures; the dust compartments are totally inclosed so that the dust is not exposed to the air current.

The bureau has tested and found satisfactory four different types of rock-dust barriers, namely, the trough barrier, the concentrated barrier, the door barrier, and the rock-dust stopping. The trough barrier and the concentrated barrier can be placed at any point in a mine entry high enough to permit their erection. Each type has a swinging board vane 100 feet beyond the barrier in each direction, these vanes being connected by a wire to the operating mechanism. When the explosion swings the vane it causes the barrier to dump the dust into the air current. Each type retains a certain amount of dust near the roof so that in case there is an interval of some seconds between the operation of the barrier and the passage of the flame, there will still be dust in the barrier to be dislodged by the pressure accompanying the flame and to quench the flame.

Plate 2, figure 1, shows a trough barrier in place in a mine entry. The wires connecting the barrier troughs with the vane can be seen on either side of the entry near the roof. When the barrier operates, the bottom boards drop as shown in plate 3, and a thick shower of dust falls into the entry.

Plate 4, figure 1, shows a cloud of dust caused by the discharge of the dust from one of the troughs.

Plate 4, figure 2, shows the same cloud from a different point of view.

Plate 2, figure 2, shows a concentrated barrier after a light, slow-moving explosion. Before an explosion the shelves of this

barrier are all held in position near the roof. When the explosion operates the barrier, however, the shelves fall to the positions shown, and much of the dust is discharged into the entry.

The door barrier consists of rock-dust compartments on both sides and above a mine door, the barrier being held in place by the frame of the door. If an explosion blows the frame out of position the entire barrier collapses and a large amount of dust is discharged into the air.

The rock-dust stopping consists of two vertical rows of shelves, one on each side of a stopping or wall, loaded with rock dust. In the event of an explosion the overturning of these sets of shelves, or the force of the explosion through the shelves causes the formation of a dense dust cloud that cools the flame.

ROCK-DUST BLOWER.

Plate 5, figure 1, shows a rather crude type of rock-dust blower, with a chamber into which the dust can be fed from a hopper.

Plate 5, figure 2, shows the dust being discharged through a hose. This blower is used to blow a thick cloud of dust into the air current, by which it is carried for considerable distances, when it settles down as a mantle over whatever coal dust there may be in the mine road or entry, and renders the coal dust much less likely to assist the propagation of an explosion. The machine is particularly useful in carrying the dust into entries that are accessible only with difficulty.

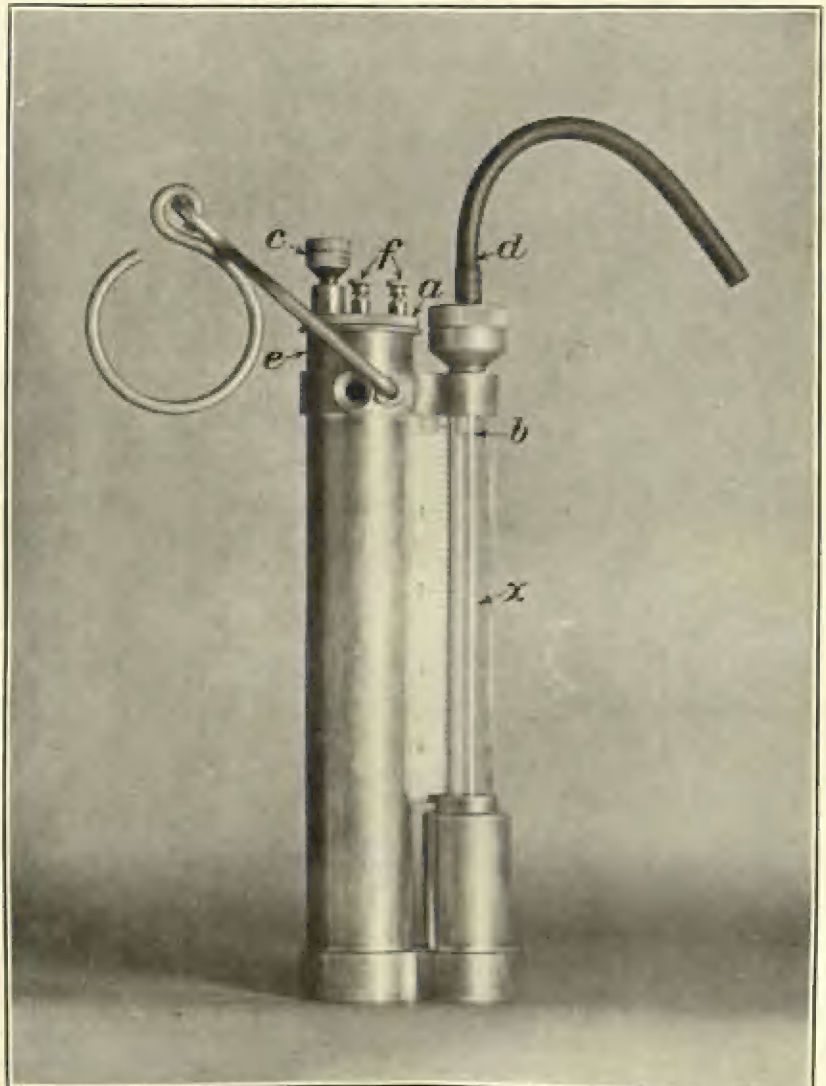
IMPROVED MINE-GAS DETECTOR.

Although the electric safety lamp, as compared with flame safety lamps, is much safer in gaseous mines, not alone because it will not under any conditions ignite the gas present, but because it gives a better illumination than the flame safety lamps, it does not take the place of the flame safety lamp in one of the latter's most important functions, namely, that of testing for the presence of dangerous gases.

There has long been a demand for some sort of an indicator or detector with which the presence of inflammable gas could be determined more accurately than with a safety lamp. Such an indicator, called the Burrell gas detector, has been developed by one of the chemists of the bureau. For determining the presence of inflammable gases it has an advantage over a flame safety lamp because its use eliminates any error due to defects of vision, and anyone can easily determine the exact amount of gas present. Thus the detector not only makes unnecessary the use of the flame safety lamp but enables the proportion of gas present to be determined to within 0.1 per cent. The flame safety lamp enables the miner to estimate only roughly the amount of gas present.

1. ROCK-DUST BLOWER.

2. DUST BEING DISCHARGED THROUGH A HOSE.



BURRELL GAS DETECTOR.

Moreover, the use of the detector is not limited to mines or to detecting fire damp, but it can be used for proving the presence of any combustible gas, such as gasoline vapor, hydrogen, natural gas, or coal gas.

Essentially, the detector consists of a U-tube, one branch of which is inclosed in a metal case, as shown in the accompanying photograph (pl. 6). To make the device ready for use the top *a* is unscrewed and water is poured in until it fills the two branches and rises to the zero point *b* on the scale.

To make a determination of combustible gas, say methane, in mine air, the valve *c* is opened, and by blowing gently into the reservoir the operator depresses the water column along the scale and forces it up to the top on the other side. A slight click when the water strikes the valve *c* tells the operator that it has risen to the required height. Then the operator pinches the rubber tube *d* and takes the instrument to the place where the sample is to be collected. When the pressure on the rubber tube *d* is released, the water immediately comes back to its original position, and on falling sucks through the valve *c* a sample of the air to be tested.

This sample rests in the combustion chamber *e* in contact with a platinum spiral. The valve is closed and the spiral is electrically heated by use of the binding posts *f*. Any combustible gas in the sample immediately begins to burn and at the end of a minute and a half is completely consumed. The electric current is then turned off and the instrument is shaken, thus forcing the water into the combustion space *e* and cooling the gases. Immediately the water column on the open-tube side falls to some point on the graduated scale as *x*, the exact point depending on the percentage of methane present. The scale reading opposite the water level shows the percentage.

The platinum wire can be heated by means of the storage battery of a miner's electric cap lamp, the battery being carried on a man's belt, and the current being switched from the lamp to the detector, as the tests are made.

The device is 10 to 20 times as accurate as the safety lamp, weighs less, and has fewer and more durable parts.

PORTABLE APPARATUS FOR RAPID DETERMINATION OF INCOMBUSTIBLE MATTER IN ROAD AND RIB DUSTS FROM COAL MINES.

In applying rock dust in mines it is necessary to determine quickly and on the spot the approximate percentage of noncombustible matter in the road and rib dust in order to determine how much additional limestone or shale dust is required to prevent the propagation of dust explosions.

For this purpose the Taffanel volumeter has been modified and combined with a convenient portable field equipment. The complete

outfit is shown in plate 7. It weighs approximately 20 pounds. The carrying case is made of $\frac{3}{8}$-inch poplar, dovetailed at the corners and brass bound, and is provided with a cover and a handle. The outside dimensions are 7 by 13 by 14 inches high, which is large enough to furnish ample room for all the required apparatus, cans of alcohol, extra supply containers, etc. The outfit consists of the volumeter *a*, the pipette *b*, the balance *c*, the funnel *d*, the alcohol can *e*, the sampling scoop *f*, the sampling cloth *g*, etc.

A determination of the percentage of combustible matter in a given sample of dust is made as follows:

Twenty-five cubic centimeters of alcohol is measured into the volumeter flask with the pipette; 20 grams of the dust to be tested is then poured in. The graduated tube is inserted in the flask, and the dust and alcohol are thoroughly mixed by shaking, after which 25 cc. more of alcohol is added from the pipette through the stem of the volumeter, all adhering particles of dust being carefully washed down.

After one minute the scale reading of the meniscus is taken, and by reference to tables the percentage of noncombustible is obtained.

The placing of this apparatus at the disposal of the employees of the bureau will enable them to determine whether the dust hazard in any mine in their district is such as to warrant treatment to prevent a dust explosion.

It is further expected that when this apparatus becomes available for general use it may result in calling the attention of mine operators to dangerous dust conditions that might otherwise eventually cause disastrous explosions.

PORTABLE APPARATUS FOR RAPID DETERMINATION OF INCOMBUSTIBLE MATTER IN ROAD AND RIB DUSTS FROM COAL MINES.

NATURAL WATERWAYS IN THE UNITED STATES.[1]

Review of Recent Progress and Present Tendencies.

By Lt. Col. Wm. W. Harts,
Corps of Engineers, U. S. Army.

[With 9 plates.]

PROBLEMS PRESENTED.

In all countries where interior waterways are used for navigation to any marked extent, there arise many complex problems, of which the most important are: First, the physical, based on the characteristics of the river, such as its discharge, slope, the permanency of its bed and banks, and the feasibility of treatment so as to make it suitable for navigation; second, the economic, based on the character and expense of the work necessary for such a purpose, together with the return on the investment that can be obtained.

These two classes of problems appeal in a more or less forcible way to different interests; the first more properly to the river engineer, and the second to those responsible for supplying funds—in the case of Government work, to Congress. Within comparatively recent years, the work of building channels has been more and more carefully studied in order to combine the best practicable solutions of all these problems, so that now no plan for a proposed river work is complete until the subject has been practically exhausted, on both the physical and economic sides, by the engineers proposing the plan.

STAGES OF INLAND-WATERWAY DEVELOPMENT.

Interior navigation in all countries has passed through several well-defined stages. The first stage antedates the use of steam as a propelling power, commencing with the time when the only means of transportation was by animals or animal-drawn vehicles, either wagons and carriages, canal boats, or pack animals. This limited source of power restricted transportation lines to highways and canals. It was not until the use of steam was successfully applied to

[1] Paper presented at a meeting of the International Engineering Congress, 1915, at San Francisco, September 20–25, 1915. Reprinted by permission of the author from the Transactions of that Congress.

the shallow-draft river steamboat that the development of interior-river channels really began. This occurred early in the nineteenth century, and afforded an enormous stimulus to the construction of new and larger canals and the improvement of natural river channels.

The second period in the history of interior navigation began with the development of the steam railways, which expanded at a surprising rate immediately after they were found practicable, particularly in those parts of the United States where ordinary roads and other means of communication were still largely undeveloped and unreliable. These railways soon entered into a vigorous competition with the rivers, canals, and highways, and before long took over a large part of their commerce.

The third period in the history of interior waterways began during the latter part of the nineteenth century, when the industrial development of the areas adjacent to streams and the increase in population had provided more than sufficient commerce for the existing railways, and had left a large volume of freight which could be more cheaply handled by water than by rail. In the United States during the first period above mentioned, the well-known canals, such as the Erie, Morris, Chesapeake and Ohio, and Delaware Canals were built, and with the advent of the steamboat a feverish eagerness to develop the river channels was felt throughout the large part of the United States extending from the Atlantic coast over the interior of the country as far west as the Mississippi River. In the succeeding years this movement increased until but few streams of any importance were without some improvement of their facilities. Notwithstanding the enormous increase in railway mileage of this country, this impulse in river development has also gone on increasing, but in many cases without much relation to the amount of commerce carried. It is only recently that this river work has begun to feel the checking effect of the railway competition, which has little by little taken from some of our streams the bulk of their commerce. Improvements in rail facilities and reduction of cost of ton-mileage have of late given the railroads an enormous advantage.

For this reason, the third stage in this country in which the river resumes its former value can not be said to have begun except in certain localities where population is much congested, such as on tidal rivers like those in the vicinity of Philadelphia, Providence, or New York City, and perhaps in a few other similar regions accessible from the ocean for comparatively deep-draft ships.

DISTRIBUTION OF WATERWAYS.

In describing the present status and recent tendencies in river engineering in this country, and in giving a general view of progress in

this important branch of the Nation's activities, only the more conspicuous instances can be referred to in a paper of this kind and only a brief general analysis given.

The work of deepening and regulating river channels in the United States has been much more extensive than is generally supposed. The amount spent on rivers, up to 1913, exclusive of harbors and canals, has amounted to $402,792,000, and there is at present river work under construction amounting to $187,064,000. New work recommended by the engineers but not yet adopted by Congress amounts to $130,315,000.

The interior natural waterways of the United States may be divided into four general divisions, corresponding to the main geographical divisions of the country. Foremost of these is the lake system along our northern border. The other divisions are the portions separated by the two main mountain ranges—the Appalachians on the east and the Rocky Mountains on the west. These divide the United States into three main portions, the Atlantic Slope, the Pacific Slope, and the Great Mississippi River Basin.

With the exception of the Hudson and the Delaware, there are but few large rivers on the Atlantic slope, and these are largely tidal. On the Pacific slope, the Sacramento and the San Joaquin Rivers form a system of navigation reaching both north and south in the State of California; and the Columbia River, farther north, offers a transportation line into the wonderfully rich and fertile Northwest.

It is in the central portion of the country, however, that the greatest opportunities for channel construction exist, for the great Mississippi Valley is traversed by one of the longest streams in the world, which, with its tributaries, offers many thousands of miles of navigable waterways.

The distribution of streams in this country and their total navigable lengths are shown in the following table:

Streams.	Streams.	Navigable length.
		Miles.
Tributary to the Atlantic Ocean	148	5,365
Tributary to the Gulf of Mexico, exclusive of the Mississippi River and tributaries	53	5,212
Mississippi River and tributaries	54	13,912
Flowing into Canada	2	315
Tributary to the Pacific Ocean	38	1,606
Total	295	26,410

(P. 28, "Transportation by Water," Report of Com. of Corporations, 1909, Part I.)

These navigable lengths must be considered as approximate, as definite lengths of navigable streams are seldom exactly determinable. Nearly all these streams are of comparatively shallow depths, and are, in the main, available for light-draft boats only. "Forty

streams have a total of about 2,600 miles of 10-foot navigation, and 70 streams give about 3,200 additional miles of navigation of from 6 to 10 feet during the greater part of the year, making a total of about 5,800 miles of 6-foot and over river navigation. The greater number of these streams flow into the Atlantic, but few of these have more than 100 miles of such navigation. The longest connected river system is the Mississippi and its principal tributaries, with about 2,500 miles of 6-foot navigation." (P. 29, "Transportation by Water," Report of Commission of Corporations, 1909, Part I.)

METHODS USED.

With the exception of the protection of the ports on the Great Lakes and the deepening of their approaches and connecting links, the main work on these waterways has been in the nature of channel development in the interior streams. It should be borne in mind that in this work greater difficulties of an engineering nature have been encountered than is usual in the streams of the older European countries, on account of the greater magnitude of the work here and the variety of the engineering problems presented, but it will be noticed that most of the successful works here have their prototypes in some of the continental rivers, where longer experience than is available here has eliminated many of the weaknesses, and enabled the later works to embrace the best of the Old World practice. It has thus resulted that there is scarcely a river or harbor project anywhere in the world in successful operation, the methods of which have not been improved upon and used somewhere in this country. Within recent years many new and original methods have also been adopted. Foremost among these new means is the invention of the suction dredge, the grapple, drag, and self-closing dredge buckets, which have reduced so markedly the cost of channel excavation of recent years; the invention of new methods of shore protection for rivers with unstable banks; the extensive use of reinforced concrete in lock and dam construction; the adoption of movable dams; and the enormous improvements in unloading machinery at terminals for ore and bulky freight.

The facilities for navigation presented by the natural waterways of the United States place it in the first rank of the nations of the world in this respect, and within the last decade much new work has been done toward making these facilities more easily available for use.

LAKE SYSTEM OF INTERIOR WATERWAYS.

It is on our northern border, where the chain of Great Lakes presents the most important system of interior natural waterways of this country, that the most conspicuous example of national benefit

is to be found. These inland seas are of enormous commercial advantage, and nowhere in this country can we point to an instance where the water routes have increased in usefulness to a greater extent than here. The depth of these lakes, the extent, and strategic location with regard to a special class of traffic make them superior in point of tonnage to any other system of interior waterways anywhere. The iron ore deposits at the western end of Lake Superior are the most important in the world; and the coal deposits in western Pennsylvania are of a magnitude and quality that make them a worthy complement to the ore fields, and well able to make the United States what it has become in the last 20 years—one of the foremost producers of iron in the world. Over one-half of the traffic of this lake system is iron ore shipped from about four ports on the western shore of Lake Superior to about a half dozen ports on the southern or southwestern shore of Lake Erie. The Lakes in themselves present excellent channels for navigation, but obstructions at the falls in St. Marys River, lying between Lake Superior and Lake Huron, were a complete bar to the navigation of these lakes, up to 1855. At this time the portage railroad previously built around St. Marys Falls, in order to make possible shipments of ore by water over the remainder of the distance, was superseded by the first lock canal around St. Marys Rapids. This canal was of comparatively small dimensions, but demonstrated the possibility of this method of handling freight. It was built by the State of Michigan, and admitted vessels drawing up to 11.5 feet, and cost about $1,000,000. This money was raised by selling 750,000 acres of public land donated by the United States Government for this purpose. In 1870 the United States undertook to widen the canal and increase the capacity of the locks, the entire existing work having been turned over to the United States by the State of Michigan and freed from tolls some years before. This new lock, known as the Weitzel Lock, was opened to traffic in 1881 at a cost of about two and two-thirds millions of dollars. Commerce responded at once to these new facilities, and in 1886 a third lock was commenced. This was built on the site of one of the old State locks and was opened to navigation in 1896. It cost about four and three-quarter millions of dollars and is known as the Poe Lock. It is 800 feet long by 100 feet wide, and admits vessels drawing up to 17.7 feet. This lock was soon inadequate, as the commerce developed more rapidly than the Government provided facilities, and in 1907 a project for an additional lock with its own separate canal was adopted at an extimated cost of $6,200,000. It will have a length of 1,300 feet in the chamber, 80 feet width, and have a depth of 24.5 feet on the sills. (See pl. 1, fig. 1.) This lock is now under construction, nearly all of lock masonry being now finished. In 1912 a project for a fourth United States lock was adopted to have

the same dimensions as the third lock, and was estimated to cost $3,275,000. It will connect with the canal of the third lock. Work on this fourth lock is also under way, the excavation for the lock pit being about one-third done.

The increased depth provided at the St. Marys Canal by the new locks made it possible to use deeper-draft vessels. This continued until obstructions in the river channels in Lake Huron and Detroit Rivers began to be felt. In 1902 a project was adopted to provide for removing shoals in the entrance to the Hay Lake Channel, a part of Lake Huron, and for securing a new outlet channel from Hay Lake by way of the old line through the West Neebish Channel. This project is now completed, affording a double channel from the Sault Locks to Lake Huron, having a clear depth of 21 feet. The expense of all this work has been $8,400,000. It is worthy of note that the increase of depth and width in the old West Neebish Channel was obtained by diverting the water from this channel by cofferdams and then excavating the rock of the old river bed "in the dry." This was the more economical method (pl. 1, fig. 2). The work took about 5 years for completion and involved the removal of 1,585,158 cubic yards of rock, at a cost of $1.36 per cubic yard, and 5,461,120 cubic yards of earth, at a cost of $0.12¾ per cubic yard, and 3,324,275 cubic yards of earth, at $0.129 per cubic yard. These amounts are exclusive of "overdepths," for which half these prices were paid.

In the Detroit River, also, there were obstructions at Limekiln Crossing, which originally limited the draft of vessels to about 12¼ feet. As this river is on the route from the Lake Superior mines to the ore ports on Lake Erie, the deepening of this obstruction was needed as soon as the locks at St. Marys River admitted deeper-draft vessels than could pass these obstructions. In 1874, a project was adopted to provide for a channel from Detroit to Lake Erie having a width of 300 feet and a depth of 20 feet. This project was modified in 1888 to provide for a width of 440 feet. In 1902 a greater depth was provided for, viz, 21 feet, and a greater width, 600 feet; and in 1910 a still greater depth of 22 feet was provided for. This channel, known as the Amherstburg Channel, is now complete, and cost $4,630,000. In 1907 a second channel was provided for, known as the Livingston Channel, and was opened to navigation in October, 1912, at a total cost of $6,734,000. This provides a separate channel for up-and-down traffic in the Detroit River.

It will thus be seen that within a decade two new locks of great capacity are being added to the others already constructed, making four in all; and the channels at the upper and lower ends of Lake Huron have been deepened and double lines for traffic provided, so that up traffic may use a different line from that going down.

These improvements have had a marked influence on freight and freight rates. In 1885 the tonnage through the St. Marys locks was 3,256,628 tons, valued at $53,413,472. In 1912 the traffic was 72,472,-676 tons, valued at $791,357,837. The average of the five years 1881–1885 was 2,399,310 tons, and for the five years 1908–1912 was 57,519,763 tons, an increase of nearly twenty-four fold. The average distance that this commerce was carried was over 800 miles. The improvement in the channels since 1900 has enabled vessels to be increased in size from 8,000 tons to 13,000 tons, and the cost of transportation has been reduced from 1.18 mills per ton mile, in 1900, to 0.67 mill per ton mile, in 1912. It was estimated that the traffic passing the St. Marys River locks in 1912 amounted to upward of sixty billions (60,000,000,000) of ton miles, and it was asserted that the saving in freight of 0.51 mill per ton-mile was directly attributable to the channel improvements. It is worthy of note that the eastbound traffic greatly exceeds that bound westward, and that it is mainly bulk freight and mainly through traffic. Over one-half of it is iron ore and one-fourth coal, the remainder being made up of flour, grain, lumber, and miscellaneous freight.

MISSISSIPPI RIVER SYSTEM.

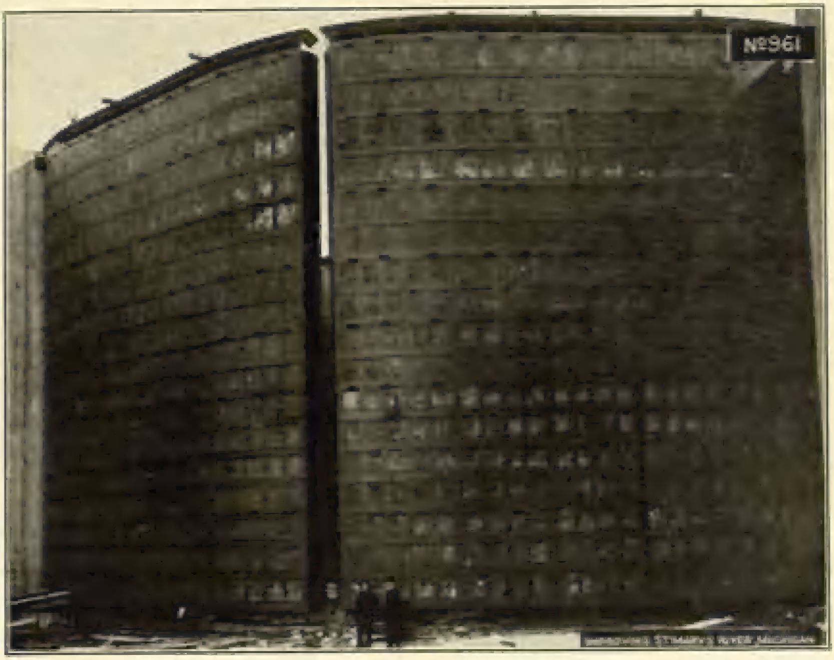
After the Great Lakes, the next most important system of interior natural waterways is the Mississippi River system. This river with its tributaries affords a navigable mileage of 13,912 miles and drains an area of about 1,300,000 square miles. In their original condition the rivers of this system were streams of shallow depth, obstructed at intervals by shoals and snags, and at certain seasons have always been subject to floods of greater or less magnitude. As a means of communication they were extensively used from the time that steam propulsion was first applied to the shallow-draft river steamboat. Before the construction of railways they were the sole means of reaching many localities, but as rail construction increased their commerce has been largely taken over by the rail lines in many cases. The most marked movement of the country's commerce is from the west to the east and reverse. North and south business is much less in volume. It thus happens that the Mississippi River and many of its tributaries do not lie along the direction of the greatest volume of traffic.

The early use of the streams depended on a successful application of steam power to a light-draft boat. The flat-bottomed shallow hull was thus a necessity. In order to get directive control in the swift currents, enormous rudders were necessary, and so the well-known gangs of three or four rudders set side by side were finally adopted; each very long, to act positively, and placed so that the preponder-

ance of the length aft of the rudder post was slight, in order to reduce the power necessary to move them. The propelling power had to be applied in such a way as to give quick strong action in flood currents and enable the rudders to act while backing. This required a powerful stern wheel. The type of boat evolved under these conditions has not changed much in recent years and its efficiency has not been increased equally with rail power. The Government, however, has endeavored to examine into this question and an appropriation of $500,000 was made in 1910 to make experiments with a view to reducing the expense of river towing on the Mississippi and its tributaries. Several experimental boats have been tried and are now being tested. Such favorable results have been met with in the twin screw "tunnel" type of steamboat that two are now being built for the lower Mississippi. Twin screws working in longitudinal tubes, or "tunnels," under and within the hull are the propelling power.

The Mississippi River is separated into three distinct parts—that above the mouth of the Ohio River, that between the Ohio and Missouri Rivers, and that below the mouth of the Missouri. In these parts the differences in the character of the river and in the methods of channel construction are conspicuous. From St. Paul to St. Louis, 658 miles, the river was originally obstructed in many places by rock rapids and sand shoals. The first plan for its deepening was adopted in 1879 and provided for a channel depth of 4½ feet over the whole distance. This was to be obtained by open river regulation. Here is to be found the most perfect instance of this class of river work in this country and is excelled in effectiveness nowhere. For many years the projected depth has been maintained throughout. The work has cost a little over $12,000,000. In 1907 it was proposed to increase the channel depth to 6 feet throughout the length of this part of the river, at an estimated cost of $20,000,000, with a view to its completion within 12 years. This project was adopted and work has been under way since then. The work is now about one-fourth done.

The available water power of the river attracted capital a few years ago, and the large market near at hand for electric power and the amount of water power going to waste induced engineers to propose a commercial enterprise which would save this waste and assist, incidentally, in the navigation of the river. Accordingly, at Keokuk, Iowa, a power dam has recently been built by private funds, which raises the water surface 40 feet. This has covered the former Government canal around the rapids at Des Moines. It has backed the river up about 60 miles, affording 6-foot navigation for this distance. It is provided with locks for passing vessels. This work is a fine example of an industry that is increasing rapidly in importance in



1. THE STEEL LOCK GATES FOR THE NEW LOCK AT THE "SOO" CANAL, MICHIGAN.

2. ROCK EXCAVATION IN THE WEST NEEBISH CHANNEL, LAKE HURON. WORK CARRIED ON WITHIN COFFERDAMS.

AN EXAMPLE OF A CAVING BANK ON THE MISSISSIPPI RIVER WHICH IT IS NECESSARY TO CONTROL.

this country, and although primarily for producing electric power, it has, incidentally, helped the navigation of the river materially.

The commerce on this part of the Mississippi has not kept pace with the industrial development of the region through which it passes. The main reason for this is said to be that the commerce consisted principally of forest products, and as these diminish in supply there is nothing that fully takes their place. The commerce of this part of the river in 1912 was as follows:

Designation.	Tons.	Ton-miles.	Valuation.
Logs	82,476	37,214,904	$409,218
Rafted lumber, shingles, etc.	10,918	3,718,643	155,482
Miscellaneous freight	1,265,589	13,469,619	25,693,493
United States material	471,311	3,506,880	425,400
Total	1,830,294	57,909,066	26,677,651

(P. 2285, Rept. of Chief of Engineers, 1913.)

This tonnage is 12 per cent less than that of the year before, and its value is 31 per cent less. Although the freight rates by water are only about two-thirds of those by rail, the disadvantages of inadequate terminals, the difficulty of transfer of freight, and risk are together apparently greater than the advantage of the lower rates afforded by the river. There has been a decrease in commerce on this portion of the river since about 1890, as is shown by the following table:

Commerce of the upper Mississippi River (Annual Repts. Chief of Engineers).

1890 ——— 4,200,000 tons (approximate), mainly logs and lumber.
1895 ——— 2,975,000 tons.
1900 ——— 2,900,000 tons (approximate).
1905 ——— 4,534,539 tons.
1910 ——— 1,916,904 tons.
1912 ——— 1,830,294 tons.

A comparison of the shipments by rail and river at St. Louis has been made by St. Louis Merchants' Exchange, and by five-year periods is as follows (p. 295, "Transportation by water," Commission of Corporations, Pt. II):

	By river.	By rail.
	Tons.	Tons.
1890	601,562	5,270,850
1895	303,365	5,349,327
1900	345,580	9,180,309
1905	80,575	13,225,973

From the foregoing it will be seen at a glance that the river commerce at this point is not encouraging for the future of river improvements. The signs all point to the fact that the facilities offered for

traffic by the river channels are now far in advance of the use made of them.

In the section between the Missouri River and the Ohio, a length of 200 miles, the character of the river changes very noticeably, and we encounter a new class of problems presented by caving banks and shifting shoals (pl. 2). These shoals are largely made of sand and gravel brought down by the Missouri in flood, and largely by the caving banks carried into the channel by scour. In this section the present project contemplates the maintenance of an 8-foot channel 200 feet wide throughout its entire length. This depth has been kept for many years, but only with constant work. In 1872 the first effort was made to deepen the shoals, which had then only 3½ to 4 feet of water on them, using solid dams and dikes of stone and brush to concentrate the low water flow into a single channel. These were only partially successful, and in 1881 the uniform depth of 8 feet was adopted for the entire section, and the use of permeable dikes and hurdles was actively begun. These were found successful in holding and consolidating the moving sediment of the river, and thus providing new banks where needed. In 1907 the project was radically changed as to methods, and since then dredging has been largely relied on for maintenance of the channel. Four hydraulic dredges of large capacity are now used in this work. Bank protection, permeable dikes, and hurdles are still extensively used, however, to produce permanent results. The last estimate of cost, made in 1903, was $21,000,000, in addition to the expenditures of about two and a half millions spent up to that time. In all about fourteen and one-half millions of dollars have now been spent, leaving over seventeen millions to complete the plan, which is now about one-third done. The use of the river for commerce has fallen off to a fraction of its former figures, notwithstanding these large expenditures. This will be shown by the following table of traffic at five-year intervals:

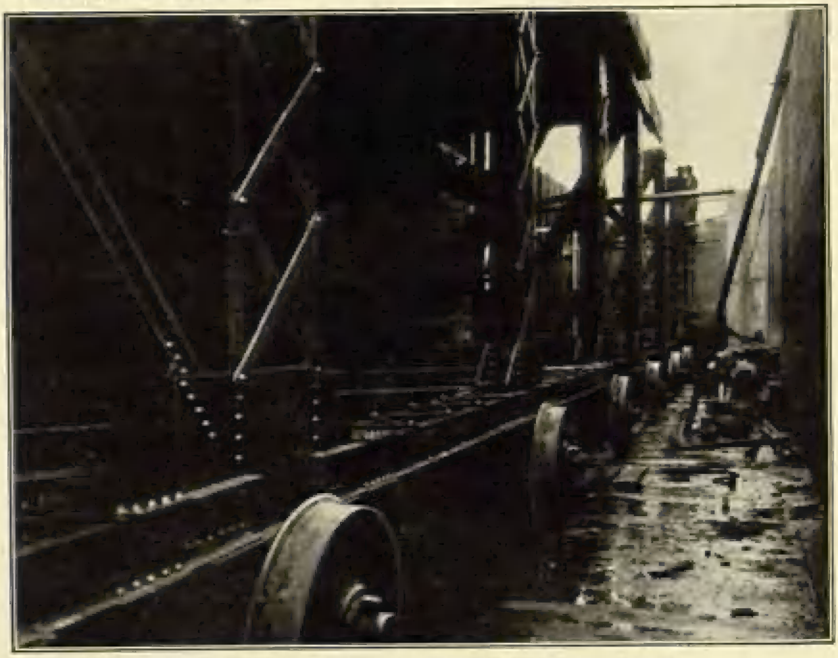
Freight traffic by five-year intervals, 1890–1912 (Repts. of Chief of Engineers).

	Tons.		Tons.
1890	1,299,670	1905	470,093
1895	838,900	1910	191,915
1900	810,230	1912	205,720

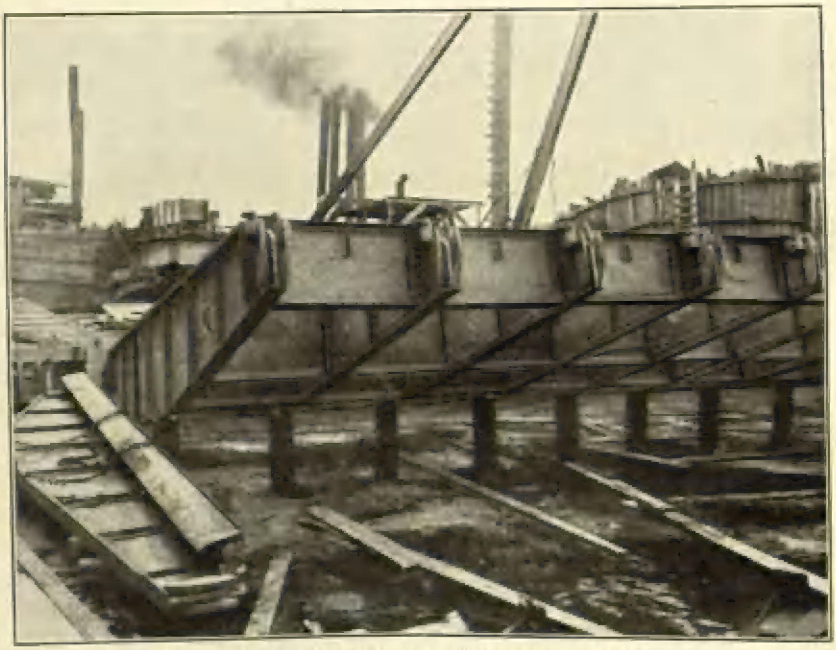
In the lower portion of the river, from the Ohio to New Orleans Harbor near the Head of the Passes into the Gulf of Mexico, a length of nearly a thousand miles has been under the charge of the Mississippi River Commission since 1879. During all this time many experiments have been tried, and much has been learned with regard to this great river. Among the most noteworthy of these lessons is the importance of protecting the banks from caving and the greater reliance that can be placed on the operation of the hydraulic dredge.

1. MAT WOVEN OF POLES AND BRUSH FOR BANK PROTECTION ON THE MISSISSIPPI RIVER. THIS MATTRESS IS CONTINUOUS, AND IS BUILT ON THE SCOW SHOWN ON THE RIGHT.

2. A FLEET OF COAL BARGES PASSING LOCK NO. 2, OHIO RIVER. THE MOVABLE DAM IS UP AND IS SHOWN ON THE LEFT.



1. A VIEW FROM BELOW OF THE OHIO RIVER LOCKS.



2. THE GATE OF A BEAR-TRAP DAM UNDER CONSTRUCTION.

In this section, the project for a minimum channel depth of 9 feet with a 250-foot width has been maintained for many years with much success. The means employed have been the narrowing of the high-water width of levees and the maintenance of the width at and near low-water stages by bank protection and by supplementing these methods by dredging on bars as they re-form. A few years ago much reliance was placed on dredging as a sole means of improvement, and nine large-capacity suction dredges were built and are still being used; but the temporary nature of the work and the high cost of maintenance of channels by this method led to the more detailed study of bank protection. Between Cairo and New Orleans there are said to be over 750 miles of caving banks, corresponding fairly well to the length of one side of the river, and it is now believed that the greater part of the sediment of the new shoals is from this source. If the banks could be held from crumbling the river would

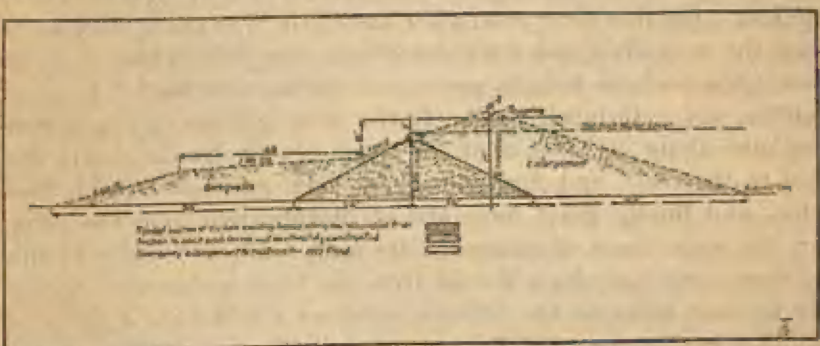


FIG. 1.—Heightening of Mississippi levees.

soon scour for itself a channel ample for navigation, and, furthermore, the protection from floods by levees would then be considerably simplified. A more serious effort is being made of late years to cut down this supply of sand by an annual extension of the bank protection (pl. 3, fig. 1), and by 1912 a total of 68.71 miles had been completed. This work at Albermarle Bend alone is estimated to diminish the amount of material brought into the river annually by 11,000,000 cubic yards. The commerce on this river has dwindled to such a small part of its former volume that protection against floods is now the most serious problem of the engineers. Experience has shown that this is best accomplished by levees, and since 1890 about half of the appropriations for the lower Mississippi have been devoted to that purpose. A new grade for levee height has recently been adopted (1914) for all United States work; but many levees have been built by State and local authorities, so but few are up to the commission's level. When breaks occur it is almost invariably in one of these low levees, and is usually caused by overtopping.

The money appropriated for this section of the river since 1879 and expended under the Mississippi River Commission amounts to over $77,000,000. Owing to the method of keeping statistics, it is difficult to determine the total commerce, as the river is divided into districts, in each of which the commerce is recorded separately. The sum of these would contain many duplications. Memphis to Vicksburg is a representative section, however, and would serve to show the tendency of commerce.

	Tons.		Tons.
1902	1,856,339	1908	1,661,406
1903	1,940,026	1909	1,252,222
1904	2,018,222	1910	1,071,037
1905	2,040,598	1911	980,386
1906	1,855,830	1912	1,910,854
1907	2,355,901	1913	1,394,789

The insignificant use now being made of this magnificent stream when compared with its capacity for transmission of freight is thus apparent. On this river soon after the Civil War there were to be found the most elaborate river steamboats ever seen in this country. Passengers, package freight, grain, and cotton were hauled in great quantity, and with much profit. In the ensuing years railroads were completed along both banks of the river, practically the entire distance to the Gulf, and first passengers, then package freight, then cotton, and finally grain have almost disappeared from the river. Now the main items of commerce are logs, sand, and coal. If this fine river could only have flowed from the neighborhood of Kansas City to some point on the Atlantic coast we might have a different condition to describe now, for the general direction of the greatest traffic movement is east and west.

At the mouth of the Mississippi there is a very excellent example of the successful deepening of river mouths in tideless seas. The necessity for this project was felt very early, and in 1854 a plan for an open river mouth was proposed by a board of three Army engineers, of whom Gens. Barnard and Beauregard were members. This plan contemplated using parallel jetties of riprap rock on mattress foundations, so spaced as to control and use for deepening the confined river currents. The mouth of the Rhone and its unfavorable experience with similar works were in part responsible for the delay in taking up this plan; but in 1875 Capt. J. B. Eads was given a contract to furnish a 26-foot channel with a 30-foot central depth through the South Pass, at a cost of $8,000,000. This sum was to cover maintenance for 20 years, or until 1901. It is now proposed to open a new channel through the Southwest Pass, 35 feet deep and 1,000 feet wide, at an estimated cost of $6,000,000. This is the present project, adopted in 1902. Already the jetties of this new project have been completed by contract, at a cost of $2,627,000, being begun

in 1903 and completed in 1908. The work of dredging the channel has been about four-fifths completed. Of 18,000,000 cubic yards of dredged material which had to be removed in 1905, less than three and one-half million yards now remain. The original depth of 9 feet has now been increased to 31 feet.

THE OHIO RIVER SYSTEM.

The Ohio River is the most important tributary of the Mississippi, and, indeed, it is the most important river of the country as a commerce carrier. In point of tonnage Pittsburgh has the largest commerce of any inland river port. This river, like all those of the Mississippi Basin, was originally shallow, crooked, obstructed by sand bars, and has always been subject to wide variation of discharge. Work was done on this stream, originally, as early as 1827. Snagging, rock removal, and bar scraping were first tried, and later the channels were deepened by placing wing dams at important places to afford a 6-foot channel depth. Notwithstanding considerable success in this direction, this did not meet all the requirements of navigation of late years, for new shoals would be formed in high water, and the uncertainties of open river regulation made the navigation precarious at low stages. But as work progressed the river channels became more reliable, and an enormous commerce, principally in coal and lumber products, grew up, owing to the favorable location of the stream, running as it did between the coal centers in western Pennsylvania and the large cities along the Ohio and Mississippi Rivers. A terminal harbor at Pittsburgh was soon needed. In order to more easily reach the important coal mines and to provide a quiet port in which loaded coal barges could be stored during low water in large numbers ready for flood stages on which they could move downstream, a dam in the upper part of the river was necessary. In 1877 one was built, and the success which this had led to the construction of several others lower down in 1890, until in 1910 a project was adopted for the canalization of the entire Ohio River, with locks and movable dams throughout its length of about 1,000 miles (pl. 3, fig. 2). This project is to provide a depth of 9 feet and is now being constructed, 14 locks and dams having been completed, 4 will be finished during 1915, and 13 are now under construction. The estimated cost of the new project is over $64,000,000 and is one of the most comprehensive plans of river improvement ever undertaken in this country. The plan provides for 54 locks, with single-leaf sliding gates instead of swinging gates (pl. 4, fig. 1), and includes dams having bear trap sections (pl. 4. fig. 2) and movable wicket sections (pl. 5, fig. 1) so arranged as to furnish pools having 9-foot channels at low stages, with all dams up. As the water

stages rise, sections of the dam are dropped until at high water no special obstruction to the flow of the river is offered, and navigation can proceed over the dam without difficulty. This project was planned to be finished in 12 years. No records of the total commerce of this stream have been compiled during recent years, but at the various locks statistics of traffic are kept. The records at the Louisville lock of the commerce passing this point have been maintained for many years. It is shown in the following table for five-year intervals, to indicate present tendencies:

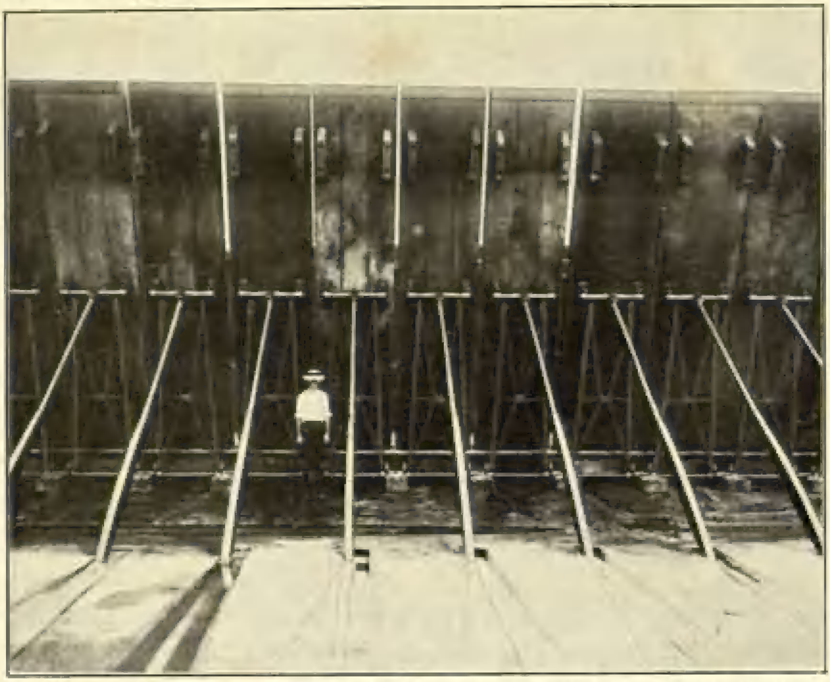
	Tons.		Tons.
1895	1,129,644	1910	1,041,323
1900	1,574,194	1913	1,446,787
1905	1,242,259		

The tributaries of the Ohio comprise an extended system of navigation which reaches a large part of the Mississippi River basin. Along these tributaries, most of which enter the Ohio from the south, are over 4,000 miles of navigable channels. Many of these tributary rivers are under improvement of a most modern and efficient type, and new projects of great interest have been begun on several within the last decade. The Kanawha River was the first to be equipped with navigable dams. The project for this work was adopted in 1875, but it was not until 1897 that the work was completed. The total cost was $4,158,000. This covered the construction of eight movable dams and two fixed dams, a system which has given a 6-foot depth throughout the length of the canalized portion of the river, of about 90 miles. Until the completion of railroads along the banks of this stream, the commerce consisting principally of coal, was of considerable size, with every indication of a marked increase in the future. This stream, like so many others in the Mississippi basin, is not maintaining its importance as a freight carrier since the completion of the principal railroads, as will be shown by the following table. Nothwithstanding a great increase in the production of coal in the region of this river, the commerce of this stream has not expanded:

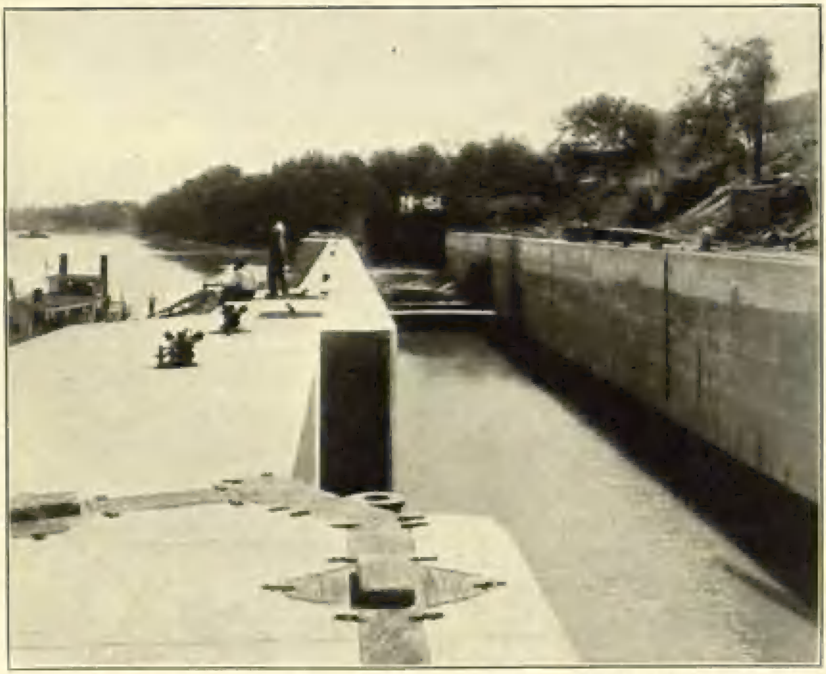
	Tons.		Tons.
1885	1,231,382	1905	1,613,889
1890	1,127,232	1910	1,122,102
1895	1,082,342	1912	1,276,540
1900	1,475,930		

The cost of maintenance during 1912 was $97,002.78. The movable dams on this river are of the Chanoine wicket type and have proven eminently successful in providing pools for 6-foot navigation. As an engineering problem alone, the solution has been very satisfactory.

The most important tributary of the Ohio, in point of traffic, is the Monongahela. On this stream are located many coal mines, par-



1. THE WICKETS OF A MOVABLE DAM ON THE OHIO RIVER, SHOWING SIGNS AND METHOD OF TRIPPING.



2. A NEW CONCRETE LOCK ON THE LOWER CUMBERLAND RIVER. THE GATES ARE NOT YET IN PLACE.

1. ROCK EXCAVATION ON THE TENNESSEE RIVER. SPECIALLY DESIGNED DRILL RAFT BORING PREPARATORY TO BLASTING.

2. CRANE BOAT ON BIG BEND SHOAL, TENNESSEE RIVER. THE GRAPPLE BUCKET HANDLES THE LOOSENED ROCK, PREVIOUSLY BLASTED, IN ONE MOVEMENT FROM CHANNEL TO TRAINING WALL.

ticularly in the lowest six pools; and many of the steel mills of the Pittsburgh district are also on its banks in the lower part. Most of the traffic of this river is coal carried to the mills of Pittsburgh, or carried to the harbor of Pittsburgh in small tows of three or four barges, there to be made up into larger tows for shipment, at high-water stages, down the Ohio to other river points below. This river is canalized, by fixed dams, throughout its entire length of 131 miles. Traffic on this stream has increased enormously in recent years. The commerce from 1890 to 1912 was as follows:

	Tons.		Tons.
1890	4,652,104	1905	9,211,752
1895	4,183,506	1910	11,486,278
1900	5,233,110	1912	11,575,289

This system of lock and dams on the Monongahela was acquired by purchase by the United States in 1897, at a cost of $3,761,651.46, and since that time three locks have been rebuilt and their dams equipped with movable tops, at a cost of about two and a quarter million dollars. In 1913, Congress ordered the rebuilding of Lock No. 6, at an estimated cost of $356,200. This river has had a very marked effect on the enormous steel industry of its region, by reducing the cost of coal. Its location is very favorable, and it has had a very important share in the development of the great steel mills of the Pittsburgh district.

It should be mentioned, however, that the statistics of 1914 show that the commerce on the 55 miles of river above Lock No. 6 is insignificant as compared with the rest of the river. Although coal is mined along this part of the stream, comparatively little is shipped by water. The economic value of Locks Nos. 7 to 15 inclusive is thus seen to be slight. The reason for this is not apparent.

The Allegheny River, which joins with the Monongahela to form the Ohio, is mostly used in the lower 25 miles, where up-stream navigation is the main movement of traffic consisting mostly of Monongahela River coal for the steel mills along the lower 6 miles of the stream. Practically no coal comes down the Allegheny, for the reason that the coal fields, which are said to be as extensive as in the Monongahela Valley, are of thin veins and so can not yet compete with the Monongahela mines. In this lower 25 miles the locks and dams were completed, No. 1 in 1903, No. 2 in 1906, and No. 3 in 1904, all at a cost of $1,690,000. In 1912, a new project was adopted by Congress providing for extending slack-water navigation about 36 miles farther up-stream by constructing five new locks and dams, at an estimated cost of $2,788,000. No work has been done on this new project because of a provision of law which requires that before work can be begun satisfactory assurance must be given that the channel spans of bridges which obstruct the river at Pittsburgh will be modi-

fied so as not to be in the way of vessels navigating the river. The commerce of this river for five-year periods is shown as follows:

	Tons.		Tons.
1900	2,570,900	1910	1,181,963
1905	1,230,352	1912	1,667,126

Nearly all of the tributaries of the Ohio of any considerable size have been canalized, many within the last two decades. The Muskingum River had been provided with locks and dams for 6-foot navigation by the State of Ohio and a private corporation between 1837 and 1841. This system was in a dilapidated state when taken over by the United States, in 1888, for rehabilitation, and at that time 10 new locks were authorized, in addition to the repairs, and, later, another lock, known as No. 11, was provided for. This project has been completed for several years. The total cost for repairs and maintenance since 1888 has been $2,050,000. The commerce has been slight, as is shown below:

	Tons.		Tons.
1910	58,956	1912	64,214

The Little Kanawha, too, was equipped with locks and dams at an early date by a private corporation. It was not until 1905 that the United States purchased the four locks in the lower river, at a cost of $163,000. Before this, a fifth lock had been built by the Government, in 1891, above the lower locks. The total money expended on this river was $281,000, by which the 4-foot navigation of the river has been restored and extended up-stream for 48 miles. Commerce has not been important, and consists principally of logs and railroad ties, materials best transported in rafts at high stages without the aid of locks and dams. During the last 24 years, the commerce has been as shown below, during 5-year intervals:

	Tons.		Tons.
1890	140,115	1905	106,510
1895	179,240	1910	84,475
1900	119,439	1912	89,202

During the year 1912, $14,500 was expended in maintenance alone.

The Big Sandy River is another tributary where locks and dams have been built within comparatively recent years, but where the commerce has always been unimportant. Three locks and dams of the movable needle type have already been built in the main river, 27 miles long, and the present project provides for the continuance of the work up-stream by building eight locks and dams on the Tug Fork and on the Levisa Fork, the two branches forming the river. These forks are also to be provided with 6-foot depths of channel, under the project. One lock and dam has been built on each fork, but it is now very unlikely that the others will ever be built—certainly not for many years—as a reexamination into the worthiness of

these streams for further expenditures has been recently reported upon adversely. The cost of the five completed locks and dams has been $1,558,000. The commerce consists principally of logs and railroad ties. It was originally hoped to reach the undeveloped coal fields at the headwaters of the forks by the river navigation, but the construction of railroads has made the extension of the slack water unnecessary and unprofitable. Commerce in recent years has been as follows:

	Tons.		Tons.
1890	268,582	1905	152,077
1895	545,910	1910	147,725
1900	300,000	1912	188,743

A conspicuous instance of the extension up-stream of the slack-water system of one of these streams, long after the commerce has declined to an unimportant figure, is the Kentucky River. The lower five locks of this system were constructed by the State of Kentucky in the years immediately following 1835, but they had grown useless and dilapidated, due to neglect, long before the year 1879, when they were turned over to the United States for restoration. These locks were restored at considerable expense, and a new project adopted soon after, involving the construction of 14 new locks and dams, to extend the 6-foot navigation up to Beattyville, at the headwaters, where it was hoped the coal veins would supply a volume of traffic that would justify the high cost of the work. If any hope of such a traffic was ever warranted, the railroads have since made it improbable of fulfillment. The estimated cost of the proposed work was $4,865,550. Of this amount $3,870,000 has now been spent, and all the system completed except the two uppermost locks and dams. The principal present commerce of the river is logs and railroad ties, which are best floated down stream, at high water, in rafts. In 1912 the commerce amounted to 186,300 tons. Previous years show a falling off of business in spite of the greatly increased length of channel available. The commerce was as follows:

	Tons.		Tons.
1890	310,354	1905	124,871
1895	296,318	1910	263,785
1900	162,891	1912	186,300

We see here an expensive system, costly to build and costly to maintain, without enough commerce to warrant the outlay. This result was predicted 20 years ago by the local engineers, but without effect. The Beattyville coal can never compete with Pittsburgh coal, even along the lower Kentucky River.

Several other small streams which empty into the Ohio have canalized sections. The Wabash River, flowing south from Indiana, has one lock and dam, having a 5-foot depth over the sills and about a

5-foot lift. It furnishes a pool about 12 miles long, but at low water vessels have difficulty in reaching the pool from the Ohio as, in fact, is true of many of the tributary streams. This lock was built in 1895 and cost over $260,000. The maintenance charges during 1912 were $7,651, and tonnage handled that year was 1,187 tons. Since 1897 the maintenance has cost $86,398.97. The Green and Barren Rivers likewise have canalized portions, providing 5-foot navigation from the mouth in the Ohio to Bowling Green, Ky., and Mammoth Cave, a total distance of about 219 miles. The four old State locks in Green River and the one in Barren River were purchased by the United States in 1889 and restored to a condition for use, and two new locks were built in Green River a few years later. No. 6, the last of the series, was opened in 1906. The total cost has been about $2,086,000, exclusive of the cost of the two new locks, and the cost of maintenance in 1913 has been about $89,000. The freight has been largely exchanged with Evansville, Ind., which is a market for the logs and ties which form the bulk of the traffic. Coal on Green River forms the third important item of commerce. The commerce at the lowest lock of this stream will not include some local business which is carried on in the river above, but will include through freight and will serve to indicate the change in commerce in this stream from year to year.

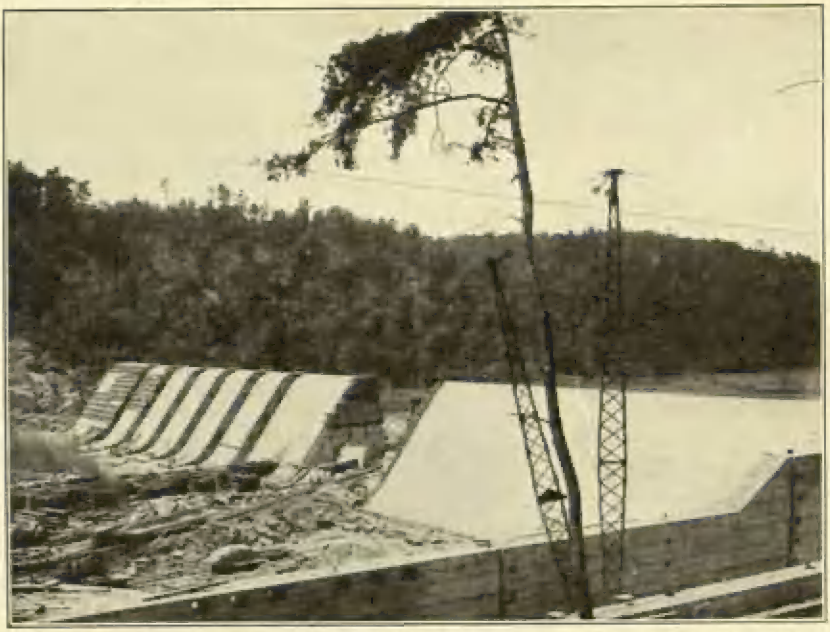
Commerce, Lock No. 1:

	Tons.		Tons.
1890	907,146	1905	466,015
1895	344,833	1910	258,199
1900	378,684	1913	302,610

Farther west the Cumberland and Tennessee Rivers empty into the Ohio. The Tennessee is over 650 miles long and the Cumberland 518 miles. On both of these streams considerable new work has been commenced within the last few years. The Cumberland has a series of seven locks, extending from Lock A, 41 miles below Nashville, upstream 166 miles, the last of which was finished in 1912, at a total cost of $2,418,952 for all seven. Lock A, below Nashville, cost $890,600, and Lock 21, near Burnside, Ky., which was built to provide a harbor at the headwaters of the river, cost $374,076. From Nashville to the mouth of the river, 193 miles, no locks were built, and the stream was in a very unsatisfactory state on account of shoals during low-water season. It was not until 1910 that the lower section, connecting with the slack-water part already finished, was provided for, at a cost of $3,165,000. This covered the cost of five new concrete locks and dams. One lock, just below Nashville, known as Lock A, had been finished in 1904, at a cost of $305,000. The work on the five new locks is now under construction (pl. 5, fig 2). The locks are to be of concrete, with steel gates and fixed concrete

1. A ROCK CUT ON THE TENNESSEE RIVER SHOWING TRAINING WALLS ALONG THE SIDES, AND A CONTRACTING SPUR ON THE LEFT.

2. HALE'S BAR DAM, TENNESSEE RIVER, UNDER CONSTRUCTION. THIS DAM HAS A 41-FOOT LIFT, AND IS BEING BUILT WITH PRIVATE FUNDS UNDER GOVERNMENT SUPERVISION FOR THE CREATION OF ELECTRIC POWER.



1. DAM NO. 17, BLACK WARRIOR RIVER, ALA., UNDER CONSTRUCTION. THIS DAM HAS A 63-FOOT LIFT, AND IS BEING BUILT BY PRIVATE ENTERPRISE FOR THE CREATION OF ELECTRIC POWER. LOOKING TOWARD THE ABUTMENT END FROM THE LOCK SIDE.

2. THE UPPER END OF THE DALLES-CELILO CANAL, COLUMBIA RIVER, OREG. SIDE WALLS OF CONCRETE CARRY THE CANAL TRUNK AROUND CELILO FALLS.

dams, and will provide for 6-foot navigation from the Ohio to Nashville and there connect with the upper river to a point above Carthage, about 160 miles farther. The nine locks now in operation cost $129,562 for maintenance in 1913. Commerce on the Cumberland has been as follows, consisting largely of logs and lumber:

	Tons.		Tons.
1890	971,563	1905	636,287
1895	321,137	1909	418,192
1900	558,371	1912	484,744

Of all the tributaries of the Ohio the Tennessee affords the greatest variety of regimen. The lower section, of about 236 miles, is somewhat like the Mississippi—a slowly flowing, crooked stream of small slope and comparatively large discharge, with low banks and soft, easily eroded bed. Dredging is the form of improvement mainly relied on for channel deepening. The next 238 miles is what is known as the "mountain section," where swift currents, rocky beds, high and rocky banks, rapids, and whirlpools are met with, requiring rock removal, canalization, and lateral canals for their treatment. In the upper section, of about 188 miles above Chattanooga, the bed and banks are fairly permanent, but the shoals and rapids make navigation difficult at low water. Here regulation by dikes and excavation tunnels is used. The river is 652 miles long and has tributaries which increase its channel length to 1,300 miles, all of which can be used by steamboats, and 1,000 miles more can be used by rafts and flatboats. Its drainage area is 44,000 square miles. The work on this stream, which began as early as 1835, was done in a rather disconnected way until 1909, when a single project for the entire stream was proposed, providing for 6-foot navigation from the mouth up to Chattanooga and 3-foot from Chattanooga to Knoxville and the upstream end. The total estimated cost was $13,000,000 and 12 years the estimate of time in which the work should be completed for most economical results. Work is now under way on this project. In the lowest section the most formidable obstruction is a rock shoal known as Big Bend. This work is noteworthy, as specially designed drill rafts are used for drilling and breaking up the bottom (pl. 6, fig. 1), and a crane boat, with a 90-foot boom and a grapple bucket, are used to remove the blasted material (pl. 6, fig. 2), the purpose being to place it in training walls on each side of the cut to act as guides for low-water navigation, and thus avoid handling a large part of the material by barge (pl. 7, fig. 1). This work is now under way. The dredging and rock removal under the new project was estimated to cost $600,000 in addition to previous work. Already $534,000 has been expended on this section to secure a 5-foot depth of channel, and the additional amount is required to get the 6-foot depth necessary and complete the deepening of the remain-

ing shoals. In the middle section are to be found the well-known Muscle Shoals, around which two canals, aggregating about 150 miles length, with 11 locks, were opened to navigation in 1890, at a cost of $3,191,726. The maintenance of this canal has cost over a million dollars since then. The use made of the canal has never reached its full capacity, but its value has been considerable to Chattanooga and Bridgeport. The completion in 1911 of the 8-mile lateral canal around Colbert Shoals, with its 26-foot lift lock, and the construction of the dam at Hales Bar for power purposes, are the most noteworthy new features of this section. The Colbert Shoals Canal was commenced in 1890 and has just recently been completed at a total cost of $2,320,000. It is 8 miles long and provides for a draft of 7 feet. The huge dam at Hales Bar was built by private persons for power purposes, and has a lift of over 41 feet. The problem of foundations presented many difficulties, but the work is now practically complete. The foundations are novel in river work in this country, and were made of concrete caissons sunk side by side in the river bed. From these the soft and imperfect rock of the river bottom was removed under air pressure and the caisson then "absorbed" in the foundation by filling with concrete. This dam and its appurtenances are said to have cost over $5,000,000, and are planned to provide 55,000 horsepower when fully developed (pl. 7, fig. 2). It is a notable example of the cooperation of private and governmental agencies to secure the fullest development of the river's resources, both in the creation of electric power and the deepening of the river for navigation. Other interesting instances of recent construction are in the Mississippi at Keokuk, Iowa, already referred to, and in the Coosa and Black Warrior Rivers in northern Alabama. In all there has been spent on the Tennessee River a total of $7,393,496, made up as follows: $328,255 in the upper section, above Chattanooga; $6,531,210 in the middle section, where the most obstructions exist; and in the lowest section $534,051. The commerce, in five-year periods, in tons, is as follows:

Section of river.	1890	1895	1900	1905	1910	1913
Above Chattanooga	77,850	265,256	380,607	480,406	370,430	474,953
Between Chattanooga and Riverton	6,474	117,357	229,160	175,800	258,750	315,218
Below Riverton	128,470	848,263	737,009	663,606	375,570	272,635

The Missouri River is the longest tributary of the Mississippi, being 2,551 miles long. Its width is from 300 feet to 1 mile, and its depth over shoals is only about 3 feet. Its banks and bed are easily eroded, and the channels frequently shift in position. At various times between 1838 and the present shoals have been deepened and snags have been removed from the channel at the worst places, but

no systematiq improvement was ever adopted until the project of 1884 was commenced, providing for revetting the banks, regulating the widths to fix the channels in location, and removing snags. In all, $14,175,378 has been expended on this river up to 1913. The work has not served to stimulate commerce, as was hoped, for the tonnage of the river remains noticeably disproportionate to the length and size of the stream. It has merely shown that a navigable channel can be obtained, although at a very great cost. The main efforts of the engineers have been directed toward the contraction of the river where necessary, rectification in other places, and securely holding the channel in place by using revetment on the banks and permeable dikes in the stream to collect and impound sediment at previously selected places. This disproportion between the high cost of an adequate channel and the small use being made of it during late years has reduced the interest in this river, and until recently the work has consisted principally in maintenance of existing conditions by protecting caving banks and removing snags. For eight years, 1884 to 1892, the river was under the direction of a commission similar to the Mississippi River Commission, but this method of administration has not been altogether successful, and it was abandoned on the Missouri in 1892. Notwithstanding these discouraging tendencies, in 1912 a project was adopted to provide a 6-foot channel, within 10 years' time, from the mouth in the Mississippi up to Kansas City, nearly 400 miles, at a cost of $20,000,000. This work is now under way, the principal reliance being put on dikes and bank revetment assisted by dredging.

The commerce of this river below Sioux City, Iowa, has been as follows:

	Tons.		Tons.
1895	154, 334	1910	876, 130
1900	263, 114	1912	249, 590
1905	343, 345		

The foregoing analysis of the largest and most important rivers in the Mississippi River system will illustrate the tendency, so much more noticeable of late years than a decade or two ago, of the diminishing part the rivers in this great basin are playing in the upbuilding of this important region. Many other smaller rivers would accentuate this important fact still more strongly. Nowhere in this country are the products of the farms more abundant; nowhere are the mines more productive; nowhere is the industry of the population accomplishing more than in this vast area. Commerce is increasing by enormous strides, and rail lines have multiplied their branches. The total commerce at St. Louis, receipts and shipments combined, was 1,265,592 tons by river, in 1890, and 15,240,141 by rail. In 1906 it was 416,855 by river and 44,964,623 by rail. During

these 16 years rail business nearly trebled in volume, and river commerce fell to one-third of its 1890 figures (St. Louis Merchants' Exchange Report). Grain has almost disappeared from the rivers. Cotton is no longer carried in quantity. The main items of river commerce are coal, sand, and forest products. Notwithstanding large sums for new improvements, nothing seems to have checked this decline in river commerce, wherever it has shown a positive tendency. With the exception of the Monongahela, and perhaps one or two other streams, the best that can be said for the busiest streams in this entire valley is that they are holding their own in tonnage from year to year, an admission in itself that the rivers are not sharing in the development of the region through which they pass.

The rivers entering the Gulf are, in general, comparatively unimportant as commerce carriers, with the exception of the Mississippi, which as a Gulf port has a river commerce which amounted to 4,273,947 tons in 1912 at New Orleans, and for the 10 years preceding it showed a substantial increase. The main Gulf rivers are those of Alabama and those of Texas. Of the former, the Alabama River with its tributaries is the most important, owing to its length of 825 miles of continuous waterway. This importance also arises from the location and direction as it proceeds from the interior of the State and flows to Mobile and the Gulf. The most recent project, that of 1910, provides for a channel 4 feet deep, at low water, and 200 feet wide, from the Mobile River, where depths are sufficient for river boats, up to Wetumpka, just above Montgomery on the Coosa River. The channels of the Coosa are partly through regulated and partly through canalized portions. Work on the Alabama River has already cost about $852,000, and on the Coosa, $2,045,000. The project for the Coosa provides for 23 locks and dams. The commerce of the Alabama in 1912 was 139,846 tons, valued at about $7,000,000; and on the Coosa, 52,342 tons, valued at a little over a million dollars. On the Coosa there is a notable example of a dam which is being built for power purposes under Government permission. It has a lift of over 63 feet and is to be provided, later, with locks for passing vessels. It is now completed and in operation. It will pond the water back for over 15 miles and will furnish a navigable channel 4 feet deep or more for that distance.

The Warrior and Tombigbee Rivers form a continuous line of water communication from the mouth in Mobile Bay up to the forks of the Warrior River and to the Warrior coal fields, about 407 miles. The Tombigbee portion, 185 miles from the Gulf up to the Warrior River, has been made navigable for 6-foot navigation by the construction of three locks and dams and by regulating work, at a cost of $1,348,000. This work is now completed. The Warrior River is to have 15 locks and dams, of which 12 have been completed and 2

provided for by recent appropriation and 1 still to be built. The total estimated cost is $9,247,000, of which $8,743,000 has already been made available by Congress. At Lock 17 a dam 63 feet high is being built by private funds for power purposes. It will be equipped with two locks in flight to pass vessels. This dam is now under construction and is practically finished (pl. 8, fig. 1). The combined commerce of these rivers is comparatively small, amounting to 464,754 tons in 1913. The cost of maintenance of 13 locks in operation in 1913 was $122,000. The high first cost and large amount needed for maintenance will require a large increase in commerce if the work is to justify the judgment of those responsible for the undertaking. Commerce since 1890 has been as follows:

	Tons.		Tons.
1890	57,868	1905	250,000
1895	87,291	1910	337,194
1900	360,950	1913	464,754

Of the Texas rivers the Trinity River is one of the longest in the State and has been navigated at favorable seasons for a distance of 120 miles upstream from its mouth in Galveston Bay. It is a narrow, shallow, winding river, with low banks. It was proposed in 1902 to provide a channel, by open river work and locks and dams, to give a 6-foot depth up to Dallas, Tex., 511 miles from Galveston, at a total cost of over $5,000,000. This project was adopted after considerable discussion in Congress, and already $1,534,000 has been expended and three locks are now completed. The water is so low in this river at certain seasons that at one time it was seriously suggested that artesian wells be used for supplying enough water to overcome the waste due to lockages and evaporation. The commerce has never been important and is now completely interrupted by the unusable condition of the river below the lowest lock. This river is another noteworthy example of the policy of providing facilities for river navigation long in advance of the necessities of commerce. One of the hoped-for results of river improvement in this instance was the regulation of rail rates from Dallas to Galveston, but legislation in Texas has already accomplished much in this direction, and the necessity for the very expensive work required is accordingly much less evident now.

PACIFIC COAST RIVERS.

On the Pacific coast the most important river in point of commerce is the Columbia River in Oregon and Washington. From its mouth in the Pacific Ocean up to the mouth of Willamette River, 98 miles, and thence up the Willamette River, 12 miles, to Portland, this waterway forms a very important artery of trade. Portland, by virtue of these rivers and their channels to the sea, becomes in

reality a seaport, a fact that has been of inestimable value in the development of the enormous trade in grain and flour that has sprung up largely with the Orient and made Portland one of the first grain-exporting cities of the country. The upper Columbia, together with the Snake River, for many years formed the only means of connection between the interior and Portland. In 1888 a line of railroad was opened along the south bank of the river and later, about 1910, a second line down the north bank connecting Spokane with Portland and Seattle was put in operation. These rail lines have reduced the importance of the river as a grain carrier; but the rule of bringing seagoing ships as far inland as possible will always maintain Portland as the main seaport of the Columbia and insure, if not increase, the value of a deep channel from Portland to the sea. The first project for this channel was to provide a 20-foot depth from Portland to Astoria at the mouth. This was adopted in 1877 and was easily secured, with dikes and training walls, assisted by dredging. In 1891 the proposed depth was increased to 25 feet, and about $1,300,000 in all was spent in completing this project. In 1902 a systematic program of dredging on a still larger scale was adopted and $2,639,000 was spent, in all, on this channel up to 1913. In 1912 the project was again extended to provide for a depth of 30 feet at low water and a width of 300 feet from Portland to the head of the estuary at the ocean, and thence 26 feet over the bar in the sea. The estimated cost was $3,770,000. The extensive jetty work at the sea entrance has now resulted in a depth of 27 feet at low water on the bar, and, with a 7.5-foot tide, a draft of 27 feet can be taken to sea by observing the tides. The river channel near Portland will be provided with three dredges, a new 30-inch suction dredge having just been completed by the city of Portland. Two large suction dredges (24-inch) are now being built for the Government, and on completion there will be six large suction dredges at work on the river channels between Portland and the sea. This method is mainly relied on to secure and maintain the proposed depth of 30 feet, but contracting dikes are used at localities wherever they are found useful. Already 22 per cent of the work has been done. Commerce on this part of the Columbia River has increased steadily of recent years and in 1912 amounted to 6,840,659 tons, valued at $85,961,745. The main items are grain, lumber, coal, and dairy products. The commerce within recent years is as follows, by five-year periods:

	Tons.		Tons.
1890	1, 416, 311	1905	3, 259, 958
1895	1, 347, 155	1910	7, 834, 273
1900	1, 489, 708	1912	6, 840, 659

1. A SECTION OF THE DALLES-CELILO CANAL, COLUMBIA RIVER, OREG., SHOWING CONCRETE LINING IN THE SECTION THROUGH SAND.

2. EXCAVATION FOR A LOCK IN THE BASALTIC ROCK FOR THE DALLES-CELILO CANAL, COLUMBIA RIVER, OREG.

In the Columbia River above the mouth of the Willamette River there are still many difficult obstructions, for the character of the river changes abruptly at the Cascade Rapids, about 100 miles above Portland. Here the river has cut its way down several thousand feet through the Cascade Mountains in a narrow and precipitous rocky gorge. To overcome these rapids a canal one-half mile long was built over 20 years ago and opened to navigation in 1896. A double lock, each part of which is 462 feet long, 92 feet wide, with a depth of 8 feet on the sills and with a total lift of 24 feet, was built and has been maintained in operation since then. It has cost $3,825,000. River commerce has not developed in this upper part of the river as was originally expected, as will be seen from the statistics of recent five-year intervals. Until the channels in the upper river are made safer, a great increase could hardly be expected; and in the meantime the railroads have been completed and have taken over nearly all the increase in commerce of this prosperous region. In 1900 the commerce was 17,710 tons; in 1905, 35,166 tons; 1910, 32,794 tons; and 1913, 33,219 tons.

About 90 miles above the Cascades are the Celilo Rapids, a complete bar at present to the use of the river at all stages. Here a canal about 9 miles long is now being built, with four locks, each 300 feet long, 45 feet wide, and 7-foot depth over the sills, to overcome a total lift of 81 feet (pl. 8, fig. 2; pl. 9, fig. 1). This canal is being cut for part of its length through the basaltic rock of the locality (pl. 9, fig. 2), and the design of locks is somewhat unusual in the details of the walls and gates. The estimated cost of the work is $4,845,000, of which over $3,000,000 has already been spent and the work is now more than two-thirds completed. The original project, now discarded, provided for a boat railway on which vessels were to be raised about 10 feet above the water at the upper end and dropped 90 feet at the lower end, after being transported about 9 miles overland. The light construction of the vessels of the Columbia River and the difficulty in building a car that would be suitable for safely carrying vessels over the vertical and horizontal curves which were indispensable to the plan were some of the strong reasons which caused the abandonment of this project.

Whether the commerce of the upper Columbia River, together with that of the Snake, will ever warrant the high cost of this canal and that at the Cascades is a problem that will require many years in the future for solution. It was recommended that a portage road be built around the Celilo Rapids before commencing on the canal, in order to determine the volume and character of the commerce which might develop. This portage road could be built for about one-tenth of the cost of the canal, and could be used as a construction road if the canal were ever built. The pressure for a canal,

however, was so urgent that funds were finally provided without considering the portage road favorably, and the canal work is now well under way. The increase in the productive capacity of the rich agricultural lands of eastern Washington and Oregon and western Idaho is fully meeting the early expectations, but it remains to be seen how much the river will be used in the future as a line of commerce in competition with two parallel lines of railroad in the same valley.

At the mouth of the Columbia is a notable instance of river work, which, for the boldness of its undertaking and the success attending the work, has been widely studied and frequently commented on by river engineers. The training of the river currents over the bar in the ocean, including not only the tidal currents, but also those arising from the natural discharge of the river, are so directed as to scour greater depths, and the restriction of all useless side currents and the shelter for the channel thus created are all accomplished by double jetties of riprap so placed as to direct the dynamic effect of these currents at a particular place on the bar. Originally bar depths were from 19 to 21 feet, but already the controlling depth is 27 feet. The south jetty is to be 7 miles long, extended into the open sea, where storms are of great violence and often of long duration. The north jetty is to be 2½ miles long. The total sum expended has been nearly $9,000,000, including the cost for maintenance. The south jetty has been completed, and the north jetty has been started. A depth of 40 feet over the bar is expected when the work is nearer completion.

The Sacramento is the principal river in California. The San Joaquin River, which joins with the Sacramento at the head of Suisun Bay, is used for navigation in the tidal portion up as far as the Stockton Channel, about 45 miles, but above this point is not extensively used. The Sacramento is about 350 miles long, but the uppermost 90 miles of the river is torrential in character and not used for navigation. It is subject to numerous floods, which inundate several hundred thousand acres in the center of the State nearly every spring. Its low-water discharge is about 8,000 cubic feet per second, and at high water it has reached 640,000 cubic feet per second. Formerly the plan of channel development provided for securing 7-foot depth at low water up to Sacramento City, about 61 miles from Suisun Bay. In this bay the depths up to the mouth of the Sacramento are 14 feet and over. The project also provides for a 4-foot depth from Sacramento to Colusa, 90 miles, and 2 feet to Red Bluff, about 110 miles farther. On this project over $740,000 has been spent, and the projected depths have been secured and maintained for many years. The Sacramento River and the Feather, a tributary, were very much subject, a few years ago, to deposits

washed down from the extensive placer-mining regions of the upper Feather, Yuba, and Bear Rivers, and a commission of Army engineers was organized in 1891 to protect the stream. Débris conditions are now materially improved in the placer-mining regions, owing to the restrictions imposed. This commission, in the performance of its functions, has recently proposed a plan for combining the control of floods, the impounding of mining débris, and the betterment of the navigation channels in a single project, which has been adopted recently by Congress and by the State of California, both sharing the expenses equally. This is a very unusual example of an excellent coordination of the various features of river work, and may be held up as an example to be followed on other streams. The estimated cost of the project is about $11,000,000, of which the State of California is to pay one-half and furnish the land necessary for levees and other works. The management of the construction work is to be under the direction of the Army engineers of the Government, and on completion the whole is to be turned over to the State for maintenance. Flood control, on the one hand, involving the reclamation of thousands of acres of valuable agricultural land from spring inundations, and channel development, on the other, are so related, and the additional need of restricting mining débris are all so intimately connected, that it made it essential to put one organization in charge of all the related activities in order to secure economy in operation. This new project, approved in 1910, includes the excavation of river channels by dredging, the construction of levees, using the excavated material in order to control high-water stages, and, further, involves the proper gauging of the river widths to prevent choking in the lower reaches. The river mouth is also to be widened and straightened. Mining débris is to be impounded, as far as possible, at the site of the mines. Already two large 20-inch suction dredges are at work on this project, which promises unusual results and widespread benefit. Commerce on the Sacramento amounted to 249,105 tons in 1890, 419,647 tons in 1895, 484,806 tons in 1900, 353,164 tons in 1905, 425,000 tons in 1910, and 477,292 tons in 1913.

ATLANTIC COAST RIVERS.

None of the rivers on the east coast of New England present any specially interesting or novel features in point of channel development or amount of commerce carried, except that there are a number of rivers entering bays, like the Mystic in Boston Harbor, which for a few miles partake of the character of tidal estuaries or harbors for important cities, and are the means of handling large quantities of freight, mainly coal. In general, this commerce is increasing, but this kind of stream is in a separate class; in fact, it is the only class

which the records show to be materially increasing in commerce. Most of these streams have depths of 20 feet or over and furnish ship channels of considerable importance. In general, the tendencies on the other rivers in this vicinity is to a decrease in commerce.

The Mystic River was originally 14 feet deep in its lower portion, of about two miles, but was increased in depth to 25 feet by the provisions of the project of 1899, at a cost of $136,000. The latest project, that of 1910, provides for an increase to 30 feet depth, at an additional cost of $172,000. The commerce of the river was originally incorporated in that of Boston Harbor, but in 1905 was 2,841,007 tons; 1910, 3,245,630 tons; and in 1912, 3,671,242 tons, valued at $16,000,000, 90 per cent of which was coal. This harbor is fairly representative of those of its kind in this region and shows present tendencies.

Providence River is only about 8 miles long, but is an estuary of much importance. Its original channel depth of less than 9 feet is now deepened to 25 feet, and the area of deep anchorage enormously increased. The latest projects, those of 1910 to 1913, provide for a 30-foot depth of channel and a deepening of the anchorages, at a total estimated cost of about $1,500,000. A new restriction, however, is now included; that before work can be begun the State of Rhode Island and city of Providence shall complete their proposed public terminals and other harbor works, at a cost of $2,000,000. Already the Government has spent $1,324,000 on previous work. The commerce in 1895 was 1,643,700 tons; 1900, 2,823,308 tons; 1905, 2,259,173 tons; 1910, 3,814,982 tons; and 1913, 4,585,364 tons. Commerce by water is chiefly coal. The requirements of the United States Government that local interests shall share in the expense of harbor work is a new and increasing feature of great interest.

The Hudson was one of the earliest rivers of the country to be improved by the Government. Work began even before 1822 by the State of New York, at which time the Erie Canal was opened, and in 1823 the Erie and Champlain both emptied into the pool created by the State dam at Troy, finished about that year. In the beginning the river was shallow in places and not over 4-foot depth existed over some shoals. Work by the United States began in 1834. At present a channel exists that affords a 39-foot draft from the sea up through the harbor of New York to the city wharves in the lower portion of the river and from there 30-foot depth can be found upstream for 93 miles and 24-foot for 24 miles farther. The upper stretch of 39 miles is limited to 9-foot draft except between Albany and New Baltimore, where 11 feet is available. This work has been completed many years and has cost about $5,500,000. The newest project, that of 1910, provides for 12-foot depth in the upper 39 miles, necessitating a new lock and dam near the old State dam and

considerable open channel work. This dam, with the deepening in the old channel as far down as Waterford, is estimated to cost $5,186,064. About one-fifth of this work is now done. Commerce in the last two years has declined, but this is ascribed to the uncertainty of the effect of the new Erie Canal and the abandonment of the river ice houses. The commerce in 1900 was 5,070,800 tons; 1905, 3,513,545 tons; 1910, 5,033,360 tons; and 1912, 3,045,136 tons, valued at $172,107,996.

Harlem River and Spuyten Duyvil Creek together form a waterway 8½ miles long, connecting Long Island Sound with Hudson River along a line north of New York City. The deepening of this waterway has resulted in a new channel which enables freight to be brought by water to a very large manufacturing region in upper New York City. Its commerce has increased very markedly of late years. Originally the channel was narrow and crooked and only 4 to 6 feet deep. The project of 1878 provided for a channel 15 feet deep and 350 feet wide, at an estimated cost of $2,100,000. The proposed width has now been increased to 400 feet and the project has been further amplified from time to time and the estimate finally increased to $3,500,000. Up to 1913 $1,683,000 had been spent and about 44 per cent of the work done. Full depths are not yet available at Macomb's Dam and near East Two Hundred and Tenth Street, but elsewhere the project is practically done.

Commerce in—

1893	3,384,468 tons.
1895	7,533,594 tons, valued at $208,707,376.
1900	4,474,687 tons.
1905	9,998,021 tons, valued at $270,210,309.
1910	12,822,885 tons.
1912	15,376,742 tons, valued at $742,508,048.

This river may be said to have reached the third stage of development, before mentioned, where the congested condition of traffic has provided so much commerce that a large share necessarily falls to the water lines. Arthur Kill is another stream emptying into New York Harbor of similar nature. Its commerce in 1912 amounted to 30,525,094 tons, valued at $515,437,656.

Delaware River is 315 miles long, but the portion from Philadelphia to Delaware Bay, 101 miles, is the part most used for navigation. In this lower portion the original depth of 17 feet has been increased materially, and the width of the channel nearly doubled. The first formal project, adopted in 1888, provided for a depth of 26 feet from Philadelphia to Delaware Bay, and a width of 600 feet. This project was completed in 1898. In 1899, it was planned to secure a depth of 30 feet. In all, $10,176,000 has been expended on this part of the river since 1834—on these two projects

and on former work. In 1910, the project was further amplified to provide a depth of 35 feet, and a channel 800 feet wide in the straight parts and 1,000 feet wide at the bends, all at an estimated cost of $10,920,000. This work involves the removal of 53,000 cubic yards of rock and over 73,000,000 cubic yards of soft dredging. Two suction dredges are now constantly at work on the new project. About $2,000,000 has been spent thus far, and the new work about one-eighth completed. In recent years the commerce has shown a healthy increase.

In 1890 it was 11,356,270 tons.
1895 it was 18,626,853 tons.
1900 it was 21,910,232 tons.
1905 it was 24,383,571 tons, valued at $1,612,847,499.
1910 it was 24,677,671 tons, valued at $1,327,869,862.
1912 it was 26,267,335 tons, valued at $1,235,106,621.

By far the largest item of this commerce is coal. It will be seen from these figures how important a part in the development of this enormous traffic the channel development has played.

The St. Johns River, in Florida, is another example of increasing traffic, fostered and encouraged by well-chosen river work. This stream was originally closed at its mouth by a bar on the ocean, over which there was only 5 to 7 feet depth at low water. By means of two jetties, supplemented by dredging, these depths have now been permanently increased to 25 feet at low water. The upper river, also, was originally interrupted by shoals of about 11 feet depth. In 1879, a project was adopted for a channel having a depth of 15 feet from Jacksonville to the sea, 27.5 miles. In 1892, it was found that the channel over the bar had been fixed in position by jetties, and the depth increased, by that time, to 13 feet at low water, and a new project for 18 feet depth of channel was thereupon adopted before the earlier work had been completed. This latter project was completed in 1894. In 1896 the proposed depth of 24 feet at low water and width of 300 feet was approved, and work was undertaken. This project was practically completed in 1910, when the present project of a 30-foot depth of channel was adopted. The newly proposed width is 300 feet in straight reaches and 600 feet at bends. On the earlier projects $4,000,000 has been expended, and on the present plan $1,266,912, and work is about half completed. This new channel has been very effective in affording cheaper lines for freight destined for northern ports and affects a large and prosperous area. Commerce has increased at a healthy rate and has justified the original estimates of growth, and apparently warranted the expenditures necessary.

The commerce in—

1890	746,895 tons.
1895	241,907 tons.
1900	649,221 tons.
1905	1,000,316 tons.
1910	2,105,820 tons.
1912	2,204,794 tons, valued at $67,877,603.

The success attending the opening of the mouth of this river in the Atlantic Ocean has been very marked. This river, together with the Columbia River and several others on the Atlantic and Pacific coasts, furnishes examples of a distinctly courageous treatment of river mouths in the open sea. This method of applying twin jetties of riprap to bar harbors has now been well tried, and is accepted as an approved method of overcoming the obstruction caused by streams and tides at the mouths of rivers emptying into tidal seas.

GENERAL OBSERVATIONS.

In conclusion, it might be well to summarize some of the more noticeable tendencies in our interior natural waterways. First, one is struck at once with the enormous increase in the commerce of the Great Lakes between the western end of Lake Superior and the harbors of northern Ohio. In spite of all efforts, it seems almost impossible to maintain facilities much in advance of the needs of navigation. New and larger locks at the "Soo," new and deeper channels in Lake Huron are scarcely complete before deeper boats and more perfect terminal facilities make these waterways inadequate to the new demands. Notwithstanding the several months of idleness in the wintertime, when ice stops all navigation, the tonnage carried has increased year by year until it has been necessary to have separate channels for upbound from those used for downbound vessels, and very much more than double the lock capacity at St. Marys Rapids. The new and extensive projects for the accommodation of this traffic seem well justified.

Second, it seems deeply disappointing to see nearly all of the rivers of the Mississippi Valley either conspicuously declining in traffic or, in a few cases, holding their own with much difficulty. Notwithstanding the adoption of the best type of locks and movable dams, the most modern and effective open river work, and the aid afforded by the Government in improving the shallow-draft river steamboats, notwithstanding huge appropriations and extensive work of the highest engineering skill, notwithstanding the enormous increase within recent years in every branch of industry in this wide area, these rivers have declined in usefulness and importance; their freight has been extensively taken over by the railroads of this region; boating has dwindled as a business until the Mississippi River itself—a stream unequalled in possibilities—now flows idly

to the Gulf with only a small fraction of its former traffic. A marked diminution in appropriations for all rivers in this valley may be expected in the next few years. Already signs are pointing to a more careful scrutiny of all work proposed in this region and to a closer study into the probable benefit to the country as a whole of the large expenditures now being made annually.

Third, it is gratifying to note the healthy growth in the commerce of many of those coastal rivers which flow into seaports and enable deep-draft vessels to reach interior cities from the sea. Coal is an important item of their cargoes, and the lowering of the cost of this commodity is widespread in benefit. This character of channel development may be expected to continue to increase in capacity as long as an increase in traffic and saving in cost of transportation can be shown. Here, too, it seems probable that new work will more than ever need to have conclusive reasons given for its adoption by the Government before it can be undertaken.

Fourth, the success in the application of the lessons learned by experience in the jetty system of deepening the entrances to rivers from the sea has been very satisfactory. The Columbia River, the Mississippi River, and the St. Johns River are all examples of difficult kinds of engineering in which Americans have been pioneers, and the results are exceptionally satisfactory. Nowhere in the world have such daring attempts been made, and nowhere have results been more effective. The great perfection of the suction dredge has so reduced the cost of channel excavation that now new channels are being deepened that before were too expensive and hazardous for even a conclusive trial, as in the case of the Ambrose Channel entrance to New York Harbor. This method of deepening, so useful in interior channels, has also been widely adopted as an auxiliary to jetty work, and is now generally recognized as a necessary aid in bar improvement. Although dredging in some harbors, as at the mouth of the Columbia, has not demonstrated its value in this place, still the results at Galveston, Mississippi River, St. Johns River, and New York, and nearly all ports on the Atlantic and Gulf coasts, have been conclusive.

Fifth, the recent, but nevertheless desirable, combination of several governmental activities in river work under a single head has been again recognized in the Sacramento River. For some years the control of floods on the Mississippi by levees has been carried on by a cooperation of the State and Federal forces, under a tacit agreement never specifically stated in the law. On the Sacramento we now find reclamation of flooded areas, control of floods, deepening of channels for navigation, and the exclusion of mining débris all included under the Federal management by law. In this work the State assists by paying one-half of the expense, by donating the

land needed for levees, and by taking over the work and maintaining it after completion. The share that the locality should pay toward a project of this character must depend mainly on the distribution of the benefit, and is debatable; but that the execution of such work should be handled as a single unit by the Government seems beyond argument. It is gratifying to note the acceptance of this principle.

Sixth, there is a recent and growing tendency to conserve the energy of our navigable rivers by private enterprise in order to develop the electric power now being wasted. This requires a cooperation between the Government on the one hand and the private interests which build the necessary plant on the other. It is seldom that a dam for the creation of electric power is just what the needs of navigation require, so there must be some adjustment or balance between the private and public requirements. Usually the company builds the dam at its own expense, and sometimes the lock in addition, and is often restricted as to the height of dam and location. The present power dam in the Mississippi River at Keokuk is completed; that at Hales Bar in the Tennessee is nearly finished; and two are under construction, one on the Warrior and one on the Coosa River in northern Alabama. It is too soon to say whether these ventures will prove to be commercial successes. It is encouraging to find that some reasonable basis can be found on which the power of a navigable stream can be conserved whenever it has a commercial value.

Seventh, the deepening of the channel of the Providence River, which has recently been made contingent on the construction by the city of Providence and the State of Rhode Island of public port and terminal facilities at their own expense, illustrates a comparatively new and very important tendency. It is more than ever expected of late that the localities benefited by Government projects will share in the expense of the work as well as in the benefits. Portland, Oreg., has undertaken to maintain at its own expense the upper part of the channel from Portland to the sea. The jetties at Siuslaw River mouth, in Oregon, will be paid for largely by the locality. The Sacramento River improvement is to be one-half paid for by the State of California, and other assistance is to be rendered. A public wharf was required to be donated by the town of Burnside on the upper Cumberland River before Lock 21 would be completed. Many other instances might be stated, so that this principle of the localities sharing in the expense of river work is now well established. In this way the earnestness of the communities urging Government work can be easily tested, and the public oftentimes assured that the channels when completed are not to be the sources of undue profit to the private owners of the only easily accessible landings.

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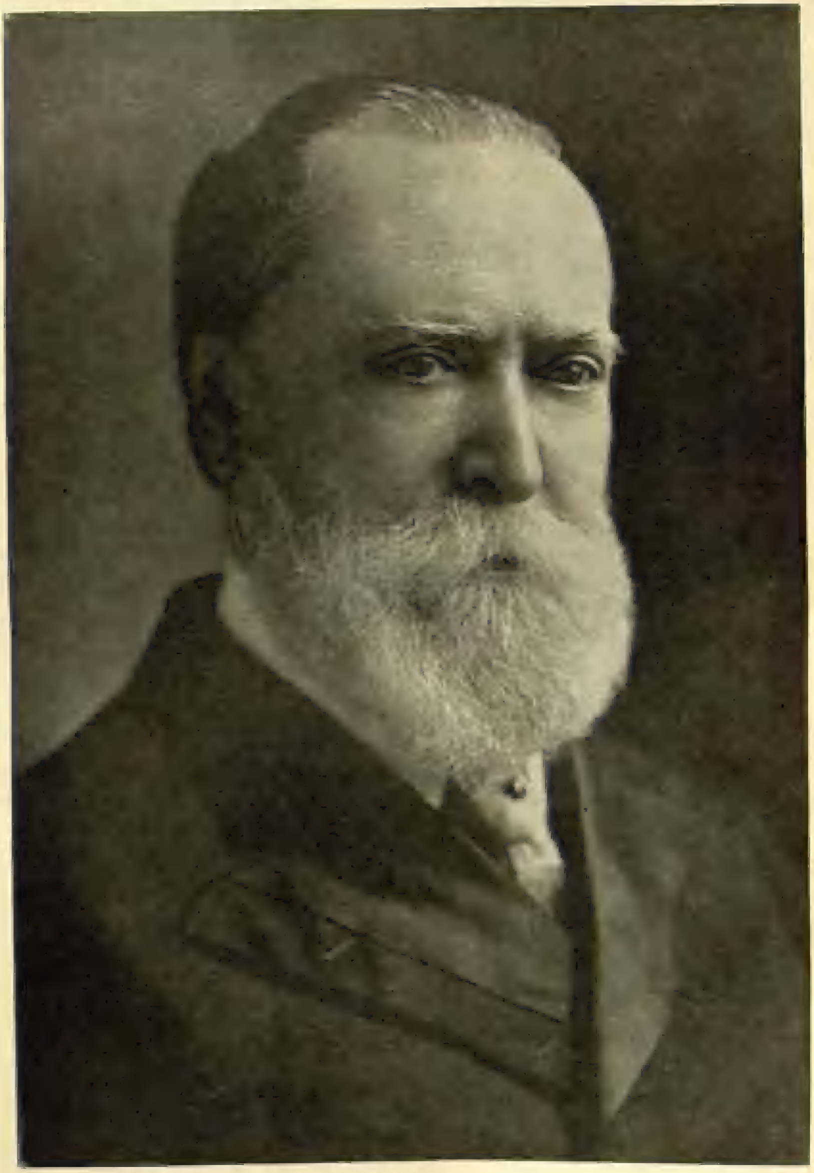

Theo. N. Gill

THEODORE NICHOLAS GILL.[1]

By William Healey Dall.

[With 1 plate.]

Dr. Theodore Nicholas Gill was born on Broadway, New York City, below the city hall, March 21, 1837, and died at Washington, D. C., September 25, 1914. He was the son of James Darrell and Elizabeth Vosburgh Gill. The father was the son of a merchant of St. Johns, Newfoundland, descended from an old Devonshire family. The mother came of old New York Dutch stock.

A few years later the family moved to 164 Grand Street, on the border of the city, which was then almost the country, with open fields, trees, and groves in plain view. The city of New York had at that time only some 300,000 population.

The boy received the rudiments of education from his mother, and at the age of 8 was sent to the Mechanics' Grammar School on Crosby Street, then a highly esteemed educational establishment.

A year later his mother died, the father gave up housekeeping, and his son was placed in charge of a private tutor at Greenville, N. Y. Here he received a very thorough training in Latin and Greek, the father having ambitions that the son should eventually become a clergyman.

Later his father married again and resumed housekeeping on West Twenty-sixth Street near Sixth Avenue, and still later moved to Brooklyn. Young Gill was then recalled from Greenville and sent to a private classical school in the city.

His love of nature and instinct for collecting developed early, and it is perhaps not merely a coincidence that, in coming by the ferry from Brooklyn and daily passing the great Fulton fish market, his attention should have been especially drawn to the study of the fishes of New York.

As young Gill arrived at the age when it seemed necessary to decide on a profession, it became evident to him that he had no taste for theological studies. After due deliberation he decided to study

[1] Reprinted by permission from Biographical Memoirs, Vol. 8, National Academy of Sciences, July, 1916. The original article contains a bibliography of all of Dr. Gill's most important contributions to systematic zoology and ecology.

law and entered the office of S. W. and R. A. Gaines, a well-known law firm of that period. The latter partner had married a sister of James Darrel Gill, and was therefore a connection interested in Theodore's success in life.

His extraordinary gift of memory doubtless enabled him to absorb the essentials of legal learning, but an overpowering tendency toward the study of nature greatly abridged his law studies and he never applied for admission to the bar. His visits to the fish market became more constant, while the adjacent water front sheltered sailing vessels from all quarters of the world, where sailors with shells and curios were daily to be encountered. His grandfather's family being residents of Newfoundland, where the fisheries were of the first importance, he kept himself informed through everything he could reach of matters relating to the subject.

The pursuit of scientific studies at that period and for a long time afterwards offered no prospect of a self-supporting career. Though there are no data on record it is reasonably certain that Gill's family must have looked with doubt, if not absolute disapproval, on his devotion to studies which did not promise even a bare living. At all events with a young family from his second marriage to bring up and educate Gill's father was not in a position to support him in an unproductive profession.

He was therefore soon left dependent on his own resources, which for years were barely sufficient to maintain his existence.

According to Dr. Gill himself we find him about this time seeking and obtaining from the Wagner Free Institute of Science in Philadelphia a scholarship which yielded him the meager means of pursuing his studies in natural history and thus coming in contact with a group of men who helped to lay the foundations of American science. This grant, he stated to a friend some time before his death, was the deciding factor in his resolve to devote himself to scientific studies.

He became acquainted with most of those who at that time in New York were interested in natural history, especially J. Carson Brevoort, whose zoological library was then reputed to be the best in the United States, and D. Jackson Stewart, a wealthy amateur, whose great collection of shells has finally found a resting place in the American Museum of Natural History.

About this time Dr. William Stimpson, the distinguished student of invertebrate zoology, while in New York heard amusing references to a young student of law who kept a horse's skull under his desk at the office where he was studying. Investigating this phenomenon further, he made Gill's acquaintance. Partly as a result of Stimpson's report to Prof. Spencer F. Baird of the Smithsonian Institution, the latter, always interested in young students of nature,

entered into correspondence with Gill and promoted his studies. A report on the fishes of New York which Gill had in preparation was accepted for publication in the annual report of the Smithsonian Institution when its author was only 19 years old.

Mr. D. Jackson Stewart in the interest of his collection financed an expedition to the West Indies and in December, 1857, Gill made his first visit to Washington and to the Smithsonian better to prepare himself for the undertaking. Here he made the personal acquaintance of Profs. Henry, Baird, and others whom he had known previously only by correspondence.

Gill sailed in January, 1858, on a large schooner, with a pleasant group of passengers.

He visited several of the Antilles, and especially Barbados and Trinidad, where he spent some weeks, being cordially assisted by many of the residents. Finding the marine fishes much the same at all the islands visited, he confined his attention especially to the peculiar fresh-water fishes of Trinidad with very satisfactory results.

After his return he devoted himself to working up this collection. He went to Washington in August, 1858, for this purpose, and stayed for several months with Stimpson. He also spent much time in Philadelphia, and his report with several subsequent papers was published in the Annals of the New York Lyceum of Natural History, the predecessor of the present New York Academy of Sciences.

In 1859 the death of his grandfather in Newfoundland made necessary a visit to that country in connection with the settlement of the estate. Gill improved the opportunity by studying the fauna of that remote region.

On his return, through Prof. Baird's intervention, he obtained an appointment with a group of workers to whom was assigned the task of reporting on the collections made during the Northwest Boundary Survey under Archibald Campbell. Among these were George Gibbs, the ethnologist, Prof. William Turner, Dr. Stimpson, and Dr. George Suckley. Dr. Caleb Kennerly, the zoologist of the expedition, had died at sea on his way home from the Pacific coast.

During this period Gill lived at the Rugby House (now the Hamilton House), where he did a large part of his work. Unfortunately, owing to the breaking out of the Civil War, the reports on the work of the commission were left mostly unpublished, Gill's among them, though some of his preliminary data appeared in the Proceedings of the Academy of Natural Sciences at Philadelphia.

Among those who were working at the Smithsonian in 1861 were F. B. Meek, the paleontologist; Thomas Egleston, afterwards professor of mineralogy in Columbia University; Dr. F. V. Hayden, the geologist; Robert Kennicott, the explorer; Prof. Matile, one of Agassiz's Swiss coadjutors in physics and at that time an assistant

of Prof. Henry; Dr. William Stimpson, who was working on the invertebrata of the North Pacific Exploring Expedition under Ringgold and Rodgers; and August Schönborn, artist, who made most exquisite silver-point drawings of Stimpson's North Pacific crustaceans.

These formed an informal association known as the Megatherium Club, whose members took meals together and foregathered with Stimpson and Kennicott for joyous evenings. The constant fluctuation in attendance, due to the coming and going between Washington and the fields of exploration in the West, tended toward disintegration, and the club virtually dissolved in a few years.

At the invitation of Prof. Henry, Gill came to the Institution in 1861, and during the following winter was appointed to the charge of its great scientific library, which had been collected and organized by that eminently capable librarian, Prof. C. C. Jewett. This post he held until 1866, when, at the instance of Prof. Henry, the Smithsonian books were deposited as a special collection in the Library of Congress. Gill went with the books to the Capitol as Assistant Librarian of Congress, and finally became senior assistant, retaining that post until 1874. All this time he had retained his quarters in the Smithsonian building, to which he hastened as soon as the usual office hours in the library were over. There most of his scientific work was done in the midst of an accumulation of books, pamphlets, unfinished manuscript, and débris of various kinds, piled on shelves, desk, and floor in a manner to strike terror to any housewife. However, old James Gant, the colored dignitary who "looked after the young gentlemen" and prided himself on having been body servant to a former President of the United States, was very willing to obey the injunction that nothing should be touched, and the accumulations continued for many years.

Finally, when the biological collections were transferred with their curators to the new National Museum building in 1909, and the room occupied by Gill formed one of those assigned to the staff of the Bureau of Ethnology, the professor was obliged to move to other quarters. He regarded the ancient heaps with dismay, and relieved himself of responsibility by presenting them, with all their contents, to the library of the Smithsonian Institution.

The earlier publications of Gill appeared in the annals of the New York Lyceum of Natural History, of which he became a member in 1858. In November, 1860, he was elected a correspondent of the Academy of Natural Sciences of Philadelphia, and for several years his papers, appearing in rapid succession, formed a large part of the academy's volumes of proceedings. With the establishment of the American Journal of Conchology in 1865, and of the American Naturalist two years later, an opportunity was utilized for printing

various communications on mollusks and miscellaneous subjects. After the starting by Prof. Baird, in 1878, of the series known as the Proceedings of the United States National Museum, most of Gill's papers were printed there, in the Smithsonian Miscellaneous Collections, or in the annual report of the institution.

When the United States Fish Commission began its work under the direction of Prof. Baird he gathered about him a number of specialists who worked up the collections, and to Prof. Gill naturally fell a large part of the taxonomic work on the fishes. Hence the annual reports of the commissioner contain numerous contributions from his pen. He was also associated with Prof. Baird in the preparation of the latter's "Annual Record of Science and Industry," published by the Harpers and its subsequent equivalent which for some years appeared in the annual reports of the Smithsonian Institution, beginning after the appointment of Prof. Baird as secretary, in 1878.

Most of the zoological data of Johnson's Cyclopedia and the zoological definitions of the Century and Standard dictionaries were furnished by Gill, though Dr. Elliott Coues acted as supervising editor.

In 1898 Gill acquired a small ornithological magazine called the Osprey and for a time associated Coues with him as editor, but the arrangement did not work well and Coues was obliged to withdraw. In 1899 Gill took entire control and with a brilliant coterie of assistant editors carried the periodical on for several years, during which he frequently contributed to its columns.

His contributions to the labors of the committee on nomenclature of the American Ornithological Union were cordially acknowledged by them, and his influence in standardizing zoological nomenclature in general has been very great, though in the main indirectly exercised.

Any classification of a large group of animals becomes obsolete with the increase of authentic data and the general progress of science; but that grasp of the subject which includes the best ideas of the current period and is joined with the capacity to weld them into a well-balanced scheme of classification is rare. It was possessed by Dr. Gill in an eminent degree. In fact, we shall hardly exceed the bounds of certitude if we call Dr. Gill the most eminent American taxonomist.

His papers were rarely long. He seemed to prefer to take up small groups, such as families and genera, and work out their relations. No great monograph exists among his publications. Their total mass, however, is very great, and their influence, especially on the classification of fishes, has been profound.

His revisions naturally met with criticism from those long familiar with the existing order. In a majority of cases he lived to see his views accepted by authorities on fishes. His ideas on Avian classification are quite different from those generally accepted, especially in regard to the relative taxonomic value of characters, but it is by no means certain that the views of future ornithologists will not much more closely approximate to those of Gill.

His work on mollusca, excepting the general classification embodied in the "Arrangement of the families of mollusks," was chiefly of the nature of revisions of particular families or genera. The "Arrangement of families" brought together the most complete knowledge existing at the time of the relations of the different groups of mollusks; but the subsequent advance of science in that respect has been relatively much greater than in mammals or fishes, and Gill's arrangement has at present chiefly an historical value.

Of the arrangement of the families of fishes and mammals others can speak with an authority denied to the present writer, but the impression left after conversation with experts is confirmatory of their exceptional value.

The present Commissioner of Fisheries has had the kindness to furnish for this memoir the following estimate of Dr. Gill's work on fishes:

Dr. Gill's chief contributions to ichthyology were his taxonomic papers. In his taxonomy, which was largely supported by his osteological research, he had no equal among his contemporaries in America or abroad. His papers represent a very large amount of painstaking investigation of a character for which he was especially well fitted and for which few active workers have the time, the fitness, or the inclination. His conclusions have been very generally accepted and form the basis for our present classification of fishes. While for years European ichthyologists disagreed with his views, his system has finally been accepted by practically all the active men at the present time. Next to his taxonomic contributions rank his papers on the structure and habits of fishes. His papers on the life histories of fishes also are noteworthy, their chief value being in the assembling and weighing of scattered observations and their presentation in form that is exceedingly helpful to all workers in this field.

His knowledge of the biological literature of all countries and all times was amazing and profound. In estimating his influence on science, full cognizance should be given to the readiness with which he placed this knowledge, together with his time and talents, at the disposal of everyone, and to the permanent value of the encouragement he was ever most anxious to give to all those who were fortunate enough to be brought in contact with him.

In noticing the death of Prof. Gill in the Annual Report of the U. S. National Museum for the year ending June 30, 1915, Mr. Richard Rathbun, Assistant Secretary in charge of the Museum, thus expresses himself in regard to his colleague and collaborator:

Rarely does one find, as in the present instance, the more or less accidental early phases in the groping for a career converge in such a manner as to at

once become useful and necessary. Dr. Gill's early training was a most fortunate one, for the splendid classical schooling of his youth gave him a complete familiarity with Greek and Latin, and his legal knowledge, combined with the former, rendered him a judge where questions of nomenclature were involved. His subsequent library training brought him in contact with the world's literature, and this, yoked with great industry and a phenomenal memory, made him the acknowledged master in his chosen field. It also produced a breadth of knowledge that rendered him a fountain of information, and, as some one has stated, "With the simplicity of the truly great and the truly able he gave freely of his stores of knowledge, so that to all the investigators who came in contact with him he proved an ever-ready source of exact and reliable information and a sound adviser." It is certain there are few workers in systematic biology in Washington and many other places who have not received assistance from Dr. Gill.

Very soon after his arrival in Washington, Gill became associated with Columbian College, afterwards Columbian University, and still later reincorporated under the name of George Washington University. In 1860 he was made adjunct professor of physics and natural history; from 1864 to 1866 and 1873 to 1884, lecturer on natural history; from 1884 to 1910, professor of zoology, and for the remainder of his life professor emeritus. The university, in appreciation of his merits, conferred upon him in 1865 the degree of master of arts; in 1866 an honorary doctorate of medicine; in 1870 the doctorate of philosophy; and in 1895 that of laws.

Dr. Gill was naturally elected to membership of many scientific societies, both at home and abroad. He became a member of the American Association for the Advancement of Science in 1868, and a fellow in 1874. In 1896 he was elected vice president of Section F, zoology, and upon the death of Prof. E. D. Cope, the president elect, he succeeded to the presidency of the association at the meeting held in 1897 at Detroit.

He was elected a member of the National Academy of Sciences in 1873, and represented the academy at the Boston meeting of the International Zoological Congress in 1898 and at the celebration of the 450th anniversary of the foundation of the University of Glasgow, Scotland, in 1901. He was a member of the American Philosophical Society, of the Philosophical Society of Washington, the Biological Society, a founder of the Cosmos Club of that city, a foreign member of the Zoological Society of London, and of some 70 other societies and scientific bodies.

As a young man, Gill was slender and rather delicate in appearance, with black hair, dark eyes, and a somewhat brunette complexion. His relatives by his father's second marriage seem to have partaken of a constitutional delicacy, as death removed many of them at a comparatively early age. I have referred to the fact that in his early manhood Gill was compelled to extreme frugality by an insufficient income. It was only in middle age that by inheritance

and some fortunate investments he reached what are generally termed "easy circumstances." The hardships of these early years left their impression on his habits, to some of which he clung with amusing pertinacity long after they seemed to his friends and relatives uncalled for. He was fond of social intercourse with intelligent people and seemed to enjoy ladies' society, but never married.

After his youthful expedition to the West Indies he traveled little, and his only visit abroad was to the anniversary celebration of the foundation of Glasgow University, in 1901. He found his recreation chiefly in books, conversation with kindred spirits, and at the meetings of the Literary Society.

An occurrence which gave great pleasure both to him and his friends was a subscription banquet tendered him at the Cosmos Club, December 13, 1912, on the completion of the seventy-fifth year of his age and the fifty-sixth year of publication of his contributions to knowledge.

On this occasion his many friends improved the opportunity of expressing their estimation of his merits as a man and a scholar and their gratitude for his many kindnesses in granting to any inquirer the benefit of his encyclopedic knowledge and phenomenal memory.

A paralytic stroke three or four years before his death permanently enfeebled him and his remaining days were quiet and uneventful.

In September, 1914, he visited his brother, Herbert A. Gill, in the lovely suburbs of Washington and a few days later was confined to his bed. On the morning of the 25th he was apparently mentally clear as usual and inquired about the news, but before noon he passed away suddenly. The interment took place at Oak Hill Cemetery.

I have to acknowledge my indebtedness to Dr. H. M. Smith, Mr. Herbert A. Gill, Mr. Richard Rathbun, Dr. Marcus Benjamin, Prof. C. H. Eigenmann, and Dr. T. S. Palmer for data furnished by them, either in print or otherwise, and of which I have freely availed myself in the preparation of this memoir.

THE LIFE AND WORK OF J. H. FABRE.[1]

By E. L. Bouvier,

Member of the Institute, Professor at the Museum of Natural History, Paris.

Fabre, the hermit of Serignan, called "the inimitable observer by Darwin, and by Victor Hugo "the Homer of insects," reached the age of 92 years in the radiance of an unsought fame that rose spontaneously from his work. He died where he had dwelt for a full half century, and his last gaze has fallen on the foliage of that henceforth celebrated spot, the rustic home of his quiet happiness, the peaceful theater of his wonderful researches. Like his life, the dying vegetation of the field bursts forth into glorious colors before entering into rest; like his work, it will not cease to be vigorous and to produce the richest bloom.

The origin of Fabre, however, was very humble and his youth beset with obstacles. Sprung from poor parents who had kept a modest market at Saint-Léons in the Rouergue Mountain, he at once was the toy of paternal vicissitudes that led him almost everywhere in the Midi and finally to the Vanclusien country, which became his adopted home. This wandering life was not at all suited to study. It prevented his remaining at the College of Rhodez, where he paid for tuition by rendering certain services and was thus compelled to educate himself. He first entered the Normal School of Avignon. This was merely the starting point, not the goal where he found his special calling. As a primary instructor at the College of Carpentras, as professor at the Lycée of Ajaccio, and finally at the Lycée of Avignon he explored with an insatiable ardor every branch of human thought. He soon became familiar with the ancient languages, and mathematical and physical sciences divulged their secrets to him. He received diploma after diploma, and became the doctor of sciences, laureate of the institute. He was a wonderful teacher. Students were spellbound by his words, and he attained unparalleled success in the free courses of secondary instruction established by him for the young girls at Avignon. But he was considered a peculiar person, wrapped up in his own researches, and, despite his success, his

[1] Translated by permission from Revue générale des Sciences. Paris, Nov. 30, 1915.

diplomas, and his early achievements, and despite the favor of Minister Duruy, who decorated him and sought to make him a preceptor of the Imperial Prince, he abandoned his alma mater and retired to Orange, then to Serignan. He must be independent, for official regulations were displeasing to his unrestrained nature; he needed the open air of the country, for his first researches had inflamed him and kindled a desire to catch the mysteries of life in their actual unfolding.

He was now free, but without means, and the expenses of his family were heavy. How then, could he supply the needs of his nestlings? This he did by ceaseless toil and an inimitable talent; the day was given to researches, the twilight and the night to works of instruction. Though he broke the chains that belonged to the professorship he still remained an apt teacher, delightfully entertaining, and so he continued to the end of his days, teaching only through his writings. In this way there appeared one after another many popular and instructive works which have been the charm of scholars since about 1870; such works as "Ravageurs des Cultures," "Auxiliaires," "Cosmographie," "Physique," "Chimie," and many other publications where the author made it a pleasure to render the most abstract scientific questions plain and attractive. Under the impetus given by Duruy, these books were introduced throughout the schools, and such were their charms that they instructed parents as well as pupils. But, apart from some didactic treatises, these smaller works were intended more to arouse interest and to attract toward science, than to lead to a diploma. They were abandoned by the schools for the undigested manuals that are laid aside with pleasure after one examination, and to the great detriment of true culture our students no longer use them. Thanks to our teachers they have been in some measure reintroduced, so that they at least find a place in the agricultural and school libraries.

That talent of explaining, that wonderful clearness, that power of arousing enthusiasm, were qualities which belonged to himself, and were part of his very nature. They are shown in the scientific works to which he owes the best of his reputation, but here combined with other qualities more striking still, a rich vocabulary and a special gift of imparting life to the subjects concerning which he wrote. He devoted his whole soul to his task, and with a passion that very quickly became communicative. His favorites were insects, those strange animals with peculiar habits. He loved them from his earliest boyhood, and had always burned with the desire to scrutinize the mysteries of their existence. Once engrossed in the fascinating subject, he was not contented to scientifically describe his heroes, but he made them alive to our gaze, in their native environment. Maurice Maeterlink said of him, "He is one of the most learned

naturalists, and the most marvelous of poets in the modern and really legitimate sense of the word."

A poet he was in his "Souvenirs entomologiques," as also in the ode on "Nombre" which resembles Victor Hugo, and in his volume of provincial chants (Oubreto prouvençalo) which brings Mistral to mind. But we must leave a domain where Maeterlink has the right to be judge, and study the "Souvenirs entomologiques" the better to know the scientific work of Fabre. This work begins with a research on the reproductive organs of the Myriapods, a doctoral thesis not devoid of good points, but which does not indicate the direction in which the author should turn to find success and fame. Fabre was no more an anatomist than a systematist. He studied actual life and the dissecting scalpel as well as the entomological pin aroused deep horror for those all ended in death. The merely chance reading of a memoir by Léon Dufour showed him "some horizons not yet suspected" and he started in the furrow "which proved to be his calling." This memoir treats of a predatory wasp of the genus Cerceris, which captures exclusively the Buprestis beetles and piles them up for its larvæ in a cell dug in the ground. The beetles first are inert and Dufour considered them as dead, but for many weeks they retain all their freshness and to explain this astonishing mystery the aged entomologist of Landes supposed that in killing them, the Cerceris inoculated them with its venom as an antiseptic to prevent decay. This hypothesis is not at all incredible; but Fabre always had a longing for the exact truth and he wanted to know all the details of the drama. As this species, *Cerceris bupresticida*, is rare in Provence he studied a hunter of weevils, *Cerceris tuberculata*, abounding in the vicinity of his home. Multiplying observations and originating some ingenious experiments, he came to a conclusion which disproved Dufour's hypothesis. The prey of the Cerceris are not dead; the wasp has struck them in the nerve centers with its sting and made them motionless by its venomous prick; rendered almost lifeless they will be defenseless and always fresh victims for the gluttonous larvæ of the Cerceris. This work inaugurated the series of entomological researches by the author. Its inherent value is very great, but its superior merit is that of introducing the experimental method into the study of the habits of insects, a method almost entirely neglected by Reaumur and by the Hubers. This method became particularly advantageous in the ingenious hands of the eager investigator who was the leader in it. It characterized all his entomological works and constituted one of his principal titles to the gratitude of learned men. It is recognized today in its full value throughout France and America where it is practiced by numerous biologists. The institute recog-

nized this new publication by awarding to the memoir on the Cerceris a prize in experimental physiology.

One of the best examples of the application of the experimental method to the biology of insects is presented by Fabre's researches on the laying of eggs by the species Osmia. The greater part of these solitary bees build their cells in cavities where most convenient, in a Helix shell, old gallery of an Anthophora, hollow stem of reeds or brambles, etc. When they lay their eggs in hollow twigs the cells are arranged in series, the largest at the bottom with the eggs first laid, the last at the top, newer and smaller in size. Now those born at the top are males, which emerge first, and the large earlier cells in turn yield females. Can the bee have the instinct for placing in each cell an egg of a desired sex? Or, rather, will the sex of the egg be determined by the food of honey and of pollen, which is less in the male than in the female cells? By some simple experiments and conclusions reached in his meager laboratory, Fabre proved without contradiction the truth of the second hypothesis. He placed the eggs of Osmia in a reed, and at the hatching time he introduced the foods, putting a large supply in the small cells and a small supply in the large cells. The result was always the same, except that the large cells yielded small females and the small cells, now well provisioned, gave large males. In a larger reed the Osmia built with more irregularity, but always placed a male egg in the small cells, a female egg in the large cells; and if it was compelled to divide its layings among narrow shells where it was impossible to arrange large cells, it laid only male eggs. From such a divided laying of 26 eggs Fabre obtained 25 males and only 1 female. Therefore the egg which comes from the ovaries does not determine the sex; but it acquires its sex in traversing the genital paths, and the female possesses the instinct of placing in each cell an egg of the sex desired. It may be said that the Osmia has knowledge of the sex of the egg that it lays and that it can produce this sex at will. This is one of the most beautiful discoveries of Fabre and is due entirely to the application of the experimental method. Without doubt the reason for the phenomenon remains unknown, and one is lost in hypotheses to establish it; but it is demanded that important works penetrate the domain of the unknown until mystery totally disappears.

To scrutinize and to follow in their enchantment the mysterious habits of insects, it does not suffice to be an ingenious experimenter; there must be a keen observation, a patience that can not be discouraged and an extraordinary intuitive power. Fabre had these qualities up to the point of genius and gave brilliant proof of it in his studies on the blister beetles of the genera Sitaris and Meloe. All that was known about the development of these insects, the so-called lice of the solitary bees, for which the genus Triungulinus had been

established, was that it is the young larva of a blister beetle, but its origin and destination were unknown. Fabre threw full light on this problem to the great surprise of biologists. The Sitaris are developed as parasites in the cells of Anthophora. They come forth in summer, are paired and lay a great number of eggs which a month later yield very active larvæ, to which has been given the name of triungulins. These larvæ pass the winter without food. In the spring they are attached to the hairs of the male Anthophora, then to the females, when the pairing is accomplished, and with these last enter into the cell of their host. Once established in this home, it devours the egg deposited by the bee on the cake of honey and pollen, moults, and comes forth in the form of a scarcely moveable fat worm with very short feet. Instead of being carniverous like the triungulin, this second form of larva is nourished by the honey cake, prepared by the bee, devours the cake entirely, moults, takes the form of an almost footless pseudo-chrysalis, and passes the winter buried in its exuvia. In the spring, moulting again, and in a new form of larva the insect remains motionless, covered with two exuviæ instead of one. At the opening of summer this third form of larva transforms into an entirely characteristic chrysalis and this one yields the adult which throws off the two exuvial envelopes in order to leave the nest of the Anthophora. These extraordinary phenomena were considered by Fabre as a hypermetamorphosis, that is, a complication of normal development. It was not at all possible to characterize them otherwise at the time they were brought to light. Since then it has been possible to follow them among numerous blister beetles and to establish their identity. The triungulin is evidently adapted to the hunt for the host. As for the pseudo-chrysalis it is considered by Edmond Perrier as a larva which is encysted at the time of high or low temperature to await a more propitious season. The Meloe, studied likewise by Fabre, is less abnormal than the Sitaris.

After all, larval polymorphism is only one of numerous chapters that Fabre has added to entomological history, and in doing this he has helped to establish the extreme pliability of insects on their coming from the egg, which serves to explain the singular predominance of these beings in the animal kingdom. The *Leucospis gigas* is a chalcidoid Hymenoptera whose larvæ devour those of the nesting bees of the genus Chalicodoma. Several females of Leucospis are likely to oviposit in the same cell of mortar which protects the future victim and this can suffice only for the nourishment of a single parasite. If all the Leucospis hatched, there would be famine. But polymorphism averts this danger. The first form of larva that issues from the egg, is very alert and provided with long hairs that measure the cell in every sense. The first hatched hastily destroys all the

other eggs, and as soon as this is accomplished there emerges a vermiform larva which "sits at the table" and sucks in its victim by mouthfuls. In another parasite of the Chalicodoma, Monodontomerus, this polymorphism is useless, for the larvæ are very small and a great number can be tabled around the nymph that serves for their nourishment. On the other hand, polymorphism is necessary among the Diptera of the genus Anthrax, which is likewise parasitic of the nesting bees. But here the primary larvæ are not exterminators: hatched outside of the cell where the Anthrax eggs are laid, their rôle is to soften the walls of mortar, so as to slip through the fissures, which readily yield to their tenuous bodies and the long terminal hairs.

The researches of Fabre on the Coleoptera of cow-dung show us habits still more diverse and perhaps more interesting. Each species has its special habitat and Fabre studied them in great numbers: the sacred beetle (Ateuchus), Onthophagus, Copris, Onitis, etc. Observation is here particularly difficult for these insects lay their eggs underground and it is at the bottom of obscure galleries that their larvæ are found; but the ingenious biologist knew well how to overcome other obstacles.

In this extensive series of works there may be chosen as an example the history of the sacred beetle, *Ateuchus sacer*, of which Fabre wrote the first chapter in the middle of the last century and the final chapter 50 years later. Since ancient times it has been known that this singular insect made little balls of dung and rolled them into a burrow where it buried itself with them; and it was acknowledged that this ball served to nourish the adult as well as its offspring. But that is nothing; though the pill is suitable for the parents, it is too coarse for the delicate intestine of the larvæ. For these last there must be a special dung, fine and well sorted, which the mother kneads into a fine pear-shaped core that will serve for a home and a covering for the future larva. Its wall is hard and the center soft, and the egg, resembling a great pearl of amber, is attached to the tip of the pear, lodged in a porous cell where the air can easily enter. Here the young larva is hatched. It gets its nourishment from the unctuous matter, and in the hard shell it will transform into the chrysalis, then into the adult. The wonderful chapters given to this history must be read to understand the difficulties that the biologist had to overcome and the rooted errors that he made to disappear. Among these last errors I will single out that which described these insects as helpful beings always ready to offer a strong hand to an embarrassed confrère. When a sacred beetle with great effort rolls its round pill, another one very often comes to its rescue; this was done, however, not in the least to render aid, but

rather to profit by an absence that might permit the stealing of the precious burden.

It would take many pages to review the results of a work lasting without respite for three-quarters of a century. I have dwelt upon certain problems solved by Fabre to bring into relief the range of his researches. To indicate the extent and the unusual character of this work I limit myself to certain of its many chapters, such as the chapter on the Lampyrids or glowworms, where we are shown the labor of these insects whose larvæ are nourished on live snails; the study of the Necrophorus that carry on the unheard-of task of burying dead bodies in which they find their subsistence; and the chapters devoted to diverse occupations of the weevils, the prickers of fruits, the cutters of young sprouts, the cigarmakers or rollers of leaves. Fabre revealed to us the cruel affections of the Mantids and the fascination that these voracious carnivores practice on their victims; the egg laying of the crickets and the peculiar maneuvers employed by their young to make their exit from the hole of the egg; the covering made by the Phryganids and the Psychids; the long evolution of the cicada in the ground; and the mechanical wanderings of the marching caterpillars. Better than McCook, he has followed the marvelous work of the orb-weaving spiders and likewise, with Moggridge, the tricks of Mygale and the burrowing Lycosids. He has given us an unparalleled description of the habits of the scorpions. What errors has he made to disappear! The resemblance of the Volucella to the wasps or the bumblebees is now known not to be attributed to a defensive mimicry, for these Diptera do not feed on parasites in the nests of their hosts, but are their destroyers. The simulation of death is a myth among the spiders as well as among the insects. Although these creatures seem to be lifeless when touched they do not adopt a defensive maneuver but present all the characteristics of a cataleptic condition: this is a new chapter added to the history of hypnosis.

Fabre always showed a predilection for the Hymenoptera which hunt and paralyze insects intended for food for their young; it is through these that he leads into the field where he became famous, and it is to them that he frequently refers in the following studies. He has reviewed nearly all of them and each one revived the ecstacies he had experienced in studying the Cerceris; the Philanthus, hunters of bees; the Ammophila that store up caterpillars; the mud-daubers and the Pompilids that attack spiders; the hunters of plant lice, of grasshoppers, of Mantids, of crickets, of flies, of beetles; all have successively been his favorites, all have brought him like astonishment. This is perhaps the most captivating part of his work; it is certainly the most extensive and the most original. Before his work

absolutely nothing was suspected of these extraordinary customs. Since then it is acknowledged that Fabre has accorded to the wasps an intensive anatomical knowledge, although many of them stab at random, and certain ones are limited to maiming their victim. The fact of pricking the nerve centers has practically been contested and the paralytic effect attributed to poison much more than to the prick. But there are some defects here as always when criticising researches of a wide range. After all, when Fabre's work is examined there is no trouble in seeing that none of these details had escaped him. He never disputed the paralytic action of the poison inoculated by the insect, and the wonderful researches by the Peckhams on the Pompilids, which hunt Lycosids, have clearly established the fact that the thrusts of the sting given by the predatory insect produce two different kinds of paralysis, one functional, and often temporary, resulting from the action of the venom, the other structural and persistent, produced by the dart which more or less injures the nervous centers.

In philosophy Fabre was a realist, opposed to hypothesis, and consequently little inclined toward comparative biology, still less to pry into past times. "Geological strata," he said, "have conserved the forms, but they are silent on the origin of instincts." He was from that time an opponent of the theories of evolutionists, which he covered with his objections, even with jeers. Intense in his studies, he was not less so in his ideas. He was spirited in discussion as well as in his work. His researches on hunting wasps gave to his mind the philosophic bent from which he never deviated. The Tachytes, which hunt Mantids, stabs at the right spot and renders helpless its formidably armed victim. It "therefore knows where the nerve centers of its prey are seated, or what is better it acts as though it knew. This knowledge, of which it is ignorant, has not been acquired by it and by its race through efforts improved from age to age and by habits transmitted from one generation to another. * * * The paralyzing power of the Mantids is more dangerous and does not allow a half success; under penalty of death, the wasp must be effective the first time. No; the surgical art of the Tachytes is not an acquired trait. Whence, then, does it come, if not from the universal knowledge on which all depends and all lives?" Fabre reaches the same conclusion for the larvæ of the Scolia, very skillful in eating the larvæ of rose-chafers (Cetoniids) paralyzed for them, but incapable of this act when they are offered another prey. He says that being in danger of death from a larva not paralyzed, they have not been able to progressively acquire the habit. Their art of eating larvæ of the rose-chafers manifested itself fully from the first. "But then, this is an inborn instinct, the

instinct that apprehends nothing and forgets nothing, the instinct unalterable by time."

In drawing his conclusions this way Fabre was dominated by the general rule and did not note exceptions. In living nature the habits of insects are the results of a series of acts which are mechanically linked, and the deviations of the mechanism are much less striking than the mechanism itself. Not that the deviations have escaped the notice of the observer; he was far too wise not to perceive them, and there was no one more keenly interested in them than was he; but he subordinated them to the general rule and did not give them the importance that most zoologists have since justly accorded to them. In fact, though widely differing from Weismann, he believed, as Weismann did, in the innate character of habits and agreed with him that habits acquired in the course of the individual existence are not hereditary. It should always be noted that Weisman, the convinced evolutionist, admits the changing of habits by germinal mutations, while Fabre, the enemy of hypotheses, shunned all explanation on this point and, with respect to the origin of habits, reverted to "universal knowledge on which all depends and all lives." He left the question open and would further say, like Montaigne: "I do not know."

Moreover, he was a man of great sincerity, and though he severely criticized the idea of evolution, nevertheless he brought out many facts that can be assigned their place to support that idea. The larvæ of hunting wasps would be incapable of touching without danger a prey different from that served to them, and Fabre observed that he could successfully serve "the larvæ of the hairy Ammophila with an adult black cricket, accepted, moreover, as willingly as its natural game, the caterpillar." He did not believe at all in the individual education of insects, and he showed us the triungulin of the Sitaris, at first seizing, like a hair of the bee, the slender straw offered to it, then, acting from experience, refusing to accept this ruse. Upon these observations and many other similar ones he founded his thesis.

"Pure instinct alone," he said, "would leave the insect disarmed, in constant conflict with circumstances. * * * In this confused melée, a guide is needed. * * * This guide the insect certainly possesses in a marked degree. This is the second domain of its psychological nature. Here it is conscious and perfects itself by experience. Not daring to call this aptitude rudimentary intelligence, a name too broad for it, I shall term it discernment." Here we are very near the most modern ideas, and very far from the German mechanist school which regards insects as simple reflex machines.

A step further and we come to pure Lamarckism, to the inheritance of habits acquired by experience. Like many other predators, the yellow-winged Sphex hollows out its burrow before starting on the chase, then returning with the prey, places it on the edge of the hole to make a last visit to his domicile. If the prey be moved a little distance, the wasp on coming out of the hole, hunts it up, brings it back to the edge of the hole and again begins a visit. This is the mechanism of instinct. "One after another, as many as forty times, I have repeated the same experiment on the same individual," reports Fabre, "and its persistence was greater than my own, its tactics never varied." But in a group studied the following year the Sphex were less stupid; after two or three experiments they frustrated the deceit and entered their home with the game. "What would you say to this?" he demanded. "The tribe that I examine to-day, the issue of another stock, for the offspring return to the home selected by the previous generation, is more skillful than the tribe of last year. The knowledge of craftiness is transmitted; some tribes are more skillful and some more stupid, apparently following the faculties of their fathers." Here we are well on the threshold of Lamarckism, for these better gifted individuals have learned from experience to be on their guard against an accident which would not be rare under natural conditions.

It seems now to be well established that the psychic evolution has been and is still effected in two ways: By short jumps or mutations, and slowly, by experience; heredity, in both cases, fixing the new habits which then take the automatic form of instincts. In spite of his ideas on unchangeable instinct Fabre has contributed more than any other man to making known the mechanism of the phenomena of evolution. Through the charm that he knew how to give to his observations he has raised up in all countries a host of eager investigators who admire him without adopting his belief. Through his exhaustive criticisms sustained by minutely controlled facts he kept evolutionists busy and has prevented them from resting on the laurels of the great masters who established the theory; finally by his works themselves he was one of the artisans who contributed the most to prove this last.

More profound than Réaumur and with a charm which Réaumur lacked Fabre has exerted and will long exert an influence equally great. He was a professor in the highest meaning of the term, and, moreover, a teacher of an entirely special kind, who dwelt alone and raised up followers by the magic of his style, the powerful interest of his works. In that as in all things is seen a perfect originality and of the highest standard. His sympathetic biographer, Dr. Legros has justly written of him, "He owed little to others, savants or

authors, and the formula of his style as well as the secret of his art are uniquely his own since he acquired them."

Fabre has proved more than anyone else the difficulties of life, but he knew how to dominate them by his own talent and by his courage in conserving intact the independence which kept him open minded and which he always considered as his most valuable asset. Modest and simple in his tastes, eager in his researches, deeply in love with the quiet country, he would taste the most profound joys in the open field where he dwelt alone among his favorite insects and the perfumed plants which there shot forth without fetters as in full nature. In this terrestrial paradise of the biologist now given to science by his devoted friends his step has traced unusual and numerous paths where henceforth continuers of his work will come for inspiration. It was there that the homage of the institute, which made him one of its correspondents, and later, the plaudits of a renown of which he never dreamed, came to find, I was about to say, to disturb him. It is there that he forever rests, leaving to new generations the example of a life made fertile by constant toil, by noble independence, and by the brilliancy of a talent that borders upon genius.

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